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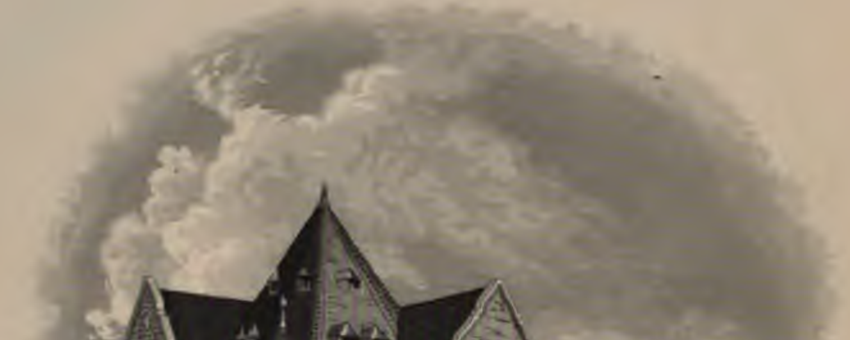

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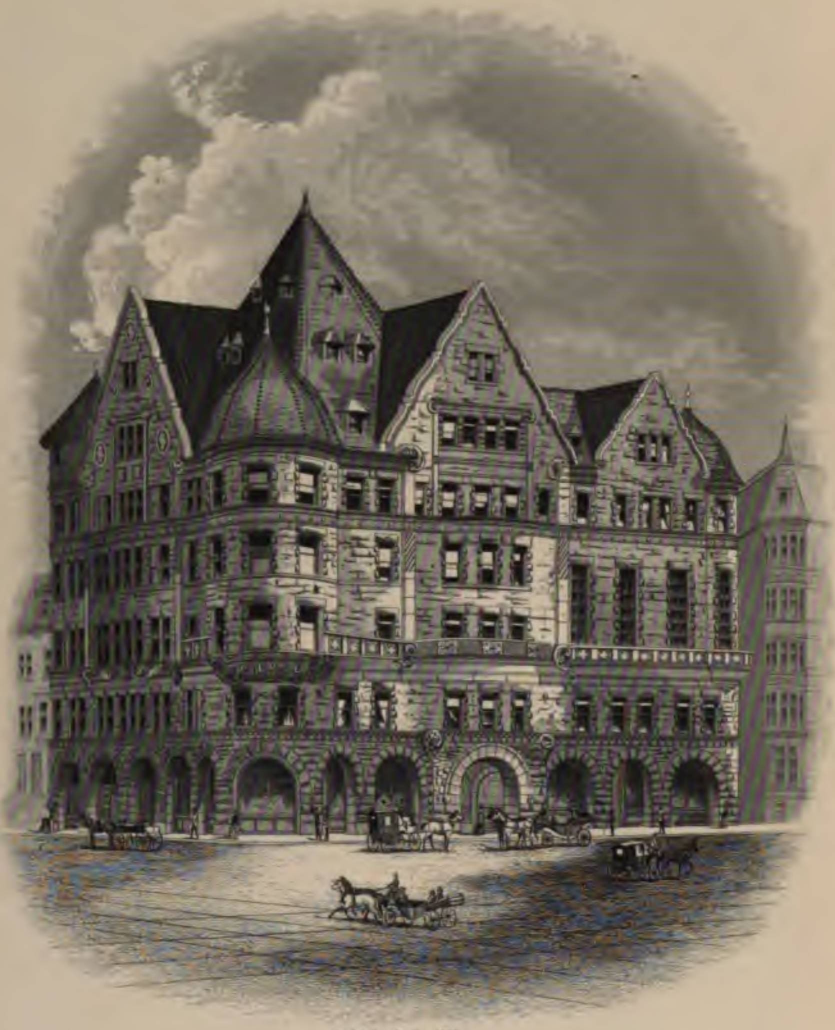

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HEAT.

SCIENCE AND PHILOSOPHY OF ITS PRODUCTION AND APPLICATION

TO THE

Warming and Ventilation of Buildings

THE ABSORBING AND TRANSMITTING POWER OF DIFFERENT

BOILER AND RADIATOR SURFACES

WITH STEAM AND WATER CIRCULATION.

VENTILATION

BY FANS AND WATER MOTORS WITH HYDRANT PRESSURE.

ALSO PLANS, TABLES AND DIAGRAMS OF EXPERIMENTAL WORK,
AND RESULTS OF ACTUAL CONSTRUCTION.

BY JOHN H. MILLS.

VOLUME 2.

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TO ARCHITECTS AND BUILDERS,

TO

ENGINEERS AND CONTRACTORS

OF

Steam and Water Heating Apparatus,

TO

TEACHERS, SUPERINTENDENTS OF PUBLIC BUILDINGS,

AND

To All Interested in the Generation and Application of Heat,

THE FOLLOWING PAGES ARE RESPECTFULLY INSCRIBED

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ACKNOWLEDGMENTS.

Having received many favors and kindnesses from others, the writer would show to friends of his early days and struggles that the talent acquired by their kindness has not, as sometimes, been buried in the sand of indifference or neglect; that if by much usury it has become five, he would fain return the interest to others who, like himself, begin life with only hope, ambition, a leaning to the sciences and mechanic arts.

To the following firms and individuals the author tenders these frank although late acknowledgments:—

The successors of Geo. W. Walker & Co., his first employers.
Walworth Manufacturing Co., of Boston, Mass.
H. B. Smith Co., of Westfield, Mass.
Providence Steam and Gas Pipe Co., of Providence, R. I.

To Engineers Charles W. Newton, Levi R. Greene, B. F. Sturtevant, Henry Williams, and others, who, realizing existing defects in the application of heat, and feeling the trammels of precedent and limited opportunity, gave freely from their store of mature experience to one who sought by practical and extended experiments to increase the common store of useful knowledge.

To John A. Whipple and Caleb Clark Walworth the writer would return his grateful thanks for their personal friendship and support, extending over a period of twenty years.

To Dr. J. B. Andrews, Superintendent of the Buffalo Insane Asylum, the writer is indebted for much personal kindness and assistance while remodeling the heating and ventilation of that Institution in 1886.

To those other readers who are living in the present rapid current of thought, invention and discovery, breasting each a wave thrown up by his own momentum, glad always to see some swimmer in the van, the thoughts, theories, and successes of a fellow-laborer may have their interest; and the writer, having cast his mite into the box of knowledge, trusts that it will not remain at the bottom without interest or benefit to those for whom it is intended.

INTRODUCTION TO VOLUME II.

FIFTY years of growth of any art or industry ought to have advanced it well on its way to perfection, and well-defined lines of theory and practice should result from all the applications and experiments made.

In any single art progress is generally commensurate with the time and talent expended upon it; but in the composite art of warming and ventilating, involving, as it does, many sciences and half the mechanical trades, progress has seemed less certain or definable, and to the half critical eye the margin for advance seems far wider than the space covered by valuable improvements.

Although water is the oldest and best agent for use in all heating operations, the least seems to be known about its merits and capabilities. It appears to have been obscured by its own forward and brilliant child, Steam, and by that vicious starveling, Hot Air, with all its train of cheap and dangerous devices. True, within the last year or two, quite a renewal of interest in water has appeared among the heating fraternity and their customers, and contractors are trimming their sails to catch the popular breeze, while the trade journals for the same reason are illustrating some old, expensive, and clumsy examples of piping for water circulation,—generally for direct radiation, and in countries and under conditions not useful or desirable for general application.

So with that other misunderstood and bedraggled science, "ventilation;" it is tossed about like a ball between the physician and the architect, as if there were anything in pharmacy, or in the combinations of wood and stone, brick and mortar, that should give a man a second sight into sciences in which he cannot, in the very nature of his education and employment, have any practical experience. True, the demand for air in a private residence or public building cannot be met without the assent and intelligent co-operation of the architect; this, unfortunately, is sometimes withheld through a lack of appreciation, or through jealousy and fear of encroachment on the exclusive control of all details, and expenditures which may affect his commission.

The author, however, has personally nothing to complain of in this line, as he has met with many competent and intelligent architects, who have done all in their power to secure good ventilation.

It is a lamentable fact, however, that owners and architects do not, as a general thing, give the subject of ventilation the consideration that it requires; no allowance for space or provisions for flues are made. Thus, when the ventilating engineer is called in, he is forced to locate the apparatus as best he can, but not always as he would like to have it. In many cases he goes to the trouble and expense of surveying the premises and making plans to heat and ventilate, or to ventilate only parts of the building, soon to be told, "You can't put a shaft there," or, "That would spoil the room," etc., etc., etc. Is it to be wondered at, that sometimes men who have devoted the best years of their lives to the study of ventilation, who are thoroughly conversant with their business, become disgusted when subjected to such treatment, and that by men who know but little about the subject of ventilation?

The author recalls but two works treating the sciences of heat and ventilation in their natural order, from the burning of fuel and tracing of its effects upon water and air, which in turn become the mediums of heat and ventilation.

The American writings of Briggs, Billings, Baldwin, and Butler contain the important and essential facts relating to the general application of what may be termed the *American* practice of warming and ventilation; while the works of Hood, Box, Williams, Clark, Tomlinson, and Schuman illustrate the *English* methods and ideas, going into the details of scientific research, and furnishing many valuable and practical tables. Yet these last, being mainly in the language of the college, and employing many figures and formulæ, render the study of principles and application of them difficult, not only to the reader of ordinary attainments, the manufacturer and builder, but almost impossible to that other and larger class, who, while being the "hewers of wood and drawers of water," are often the inventors of new machines and methods for improving the very conditions laid down by theorists and writers.

Having received much benefit from the study of these able engineers and writers, it ill becomes the author to depreciate the works and labors of those who, with far better abilities, have contributed to this library of useful information. As, however, no inventor can do useful work without a thorough knowledge of the art he would improve, he may be exempt from the charge of egotism should he review and even criticise what he considers wanting or defective in the theory or practice of those who, while aiming to instruct others, may also lead them astray.

Seeing the magnitude of the interests involved and the little practical knowledge available for the understanding of them, the author has devoted much time and money, in the way of experiments, to unravel the mysteries of *sensible, latent, radiant, and conducted heat.*

The writer's experiments on boilers and radiators were made from time to time during the last fifteen years, occupied as inventor and contractor for warming and ventilating plants in the United States and the Provinces. They were first made for his own education and benefit, and later in the interest of individuals and companies who desired practical information on particular points of construction or operation; they may thus be considered, as they are pledged to be, entirely impartial.

Recognizing that to be of value to himself or others, experiments must be accurately made, the writer has availed himself of the most approved methods and the best instruments the market afforded, while time and labor have been no consideration, provided reliable and original facts could be obtained. At the same time it should be seen that the tests were comparative, and not exhaustive, or intended to raise or depreciate the value of the machines tested.

Doubtless there will be more or less "testing," to verify the statements and conclusions here drawn, in the interests of certain goods which did not give the results claimed for them.

It is in evidence that little satisfaction will result unless experiments are conducted on a more practical basis; that some persons may not, even after all the proof offered, be "*convinced against their will*" and interest, and admit that their particular devices are not constructed on sound principles, or that there are sciences involved which they do not understand.

Having before stated that the author does not attempt to teach science to scientists, or philosophy to philosophers, he will not expect to stand on the defensive from the fire of critics or others who, having done little or nothing themselves to increase the stores of practical knowledge, object on principle to seeing it done by methods unfamiliar to them, or that have not been approved by some favorite authority. At the same time, having undertaken to show the relation of the sciences to the successful work of invention, construction, and application of heating apparatus, he does not fear a candid review of his methods and conclusions.

It was explained in the introduction to the first volume, that it was not the author's original intention to extend his work beyond three or four hundred pages, but that later it became evident it could not be stopped at any such limit, without cramping the whole plan and leaving out altogether many important matters and interests.

That any connected and worthy review of the applications of heat to buildings would require at least an equal space, was discovered, and this accounts for the second volume, and also for the delay incurred in the preparation and appearance of the work.

After deciding to bind in two volumes, it was not found easy to change all the numbers on the pages that were plated, and the references to these, and to begin the second volume at page 1, but to allow the numbers to continue in successive order. Thus Volume I. practically closes at page 302, and Volume II. begins at page 303, without taking account of the extra pages following, and a part of Volume I., or the introductory pages, contents, etc., of Volume II.

In all references to heat in the following pages, whether of boilers, radiators, or spaces treated, the subject is reduced and referred to the British thermal unit, or standard of work, which is, *the raising of one pound of water one degree Fahrenheit*, in which connection it may be well to remember that one pound of good coal (hard or soft) has fourteen thousand such heat units when burned under the proper conditions, as set forth in the chapters on combustion, and that, under the general arrangement of heating apparatus, *only seven or eight thousand units is realized, while ten to twelve thousand is possible and attained in practice, as shown by reports of engineers.*

The unit of work employed is the *foot-pound*, or the energy required to raise one pound weight against the resistance of gravitation one foot high.

The same amount of energy expended will give one pound of matter (at rest) a velocity of about *eight feet per second*, the force in this case overcoming the resistance of inertia instead of gravitation.

In the flow of gases, one foot-pound is equivalent to the discharge of one cubic foot against an opposing pressure of one pound per square foot, or 1-144 pounds per square inch.

As heat is a form of motion, energy is required to raise the temperature of matter, one unit of heat being equivalent to about 776 foot-pounds.

A man of ordinary strength can exert a force of 30 pounds, with a velocity of 2.2 feet per second = 4,500 pounds raised one foot in a minute, which is equal to .2 of the work of a horse. In working a pump, turning a winch, and in rowing a boat, the effective powers of a man are as the numbers 100, 167, 227, 248.

A *horse-power* is equivalent to the performance of 33,000 foot-pounds of work per minute. Later estimate, 22,500 pounds (= to 5 men). —*Haswell.*

ERRATA.

On the following page, 303, line 12, for 20,000 to 30,000 heat units, read 2,000 to 3,000.

CHAPTER XVII.

THE TRANSMISSION OF HEAT.—RADIATORS.

PART IV.

PASSING on in the regular order of evolution from fuels, *combustion, furnaces, steam generators, and water heaters*, we enter on a new and different field of inquiry, and one calling for finer lines and distinctions, due principally to the less differences in the factors entering into our calculations.

We have been dealing with temperatures of combustion in the furnaces of from 500° to 1,500°, and with absorbing surfaces of from 200° to 400°. We have now to consider temperatures of lower degrees —of those of steam and boiling water in the radiators, say from 100° to 250°, and that of the surrounding air at 0° to 70°.

One square foot of surfaces in the boiler will receive and transmit 20,000 to 30,000 heat units per hour, while one foot of direct radiator is limited to about 300; and it is in these proportions that they are employed as heat transmitters. To 100 feet of boiler we have about 1,000 feet of radiators, or for economical work, 600 to 700.

It might be inferred that the author would be more at home in the following chapter on radiation, the heating and cooling of air, and the transmission of heat by steam and water circulation, than in some of the deeper sciences involved in combustion, the solid and liquid fuels.

It should be remembered, however, that, while he does not pose as a theoretical teacher of the sciences, that the sciences are really the key to any explanation of the phenomena attending heat, and that we must continually lean on them, and on those writers who by birth and education are the best expounders and teachers of the sciences involved.

Of the several writers on the subject of heat, its generation and application to buildings, none have been so clear and helpful as Charles Hood,* and I judge that he has been equally good meat for a score of later writers, only they do not always do justice, and credit him with the material which they bodily carry away.

Another writer has much in his "Box" † that is of great assistance to the student and the engineer; it was from his treatment of ventilation by mechanical means, that the writer drew his inspiration, so to speak, for the lines of his fan.

---

* The Warming and Ventilation of Buildings, 1879.

† Thos. Box, Treatise on Heat, 1876.

There have been later writers, and those who lay claim to both a theoretical and practical knowledge of construction in the line of boilers and radiators; yet they do not prove as satisfactory teachers, not being as practical, or going far enough into the "reasons" for any construction or theories they advocate.

Before entering upon radiators, their practical construction and operation, it seems desirable to consider certain fundamental laws which underlie all this class of heating operations, and furnish a key, as it were, with which to unlock the tables and diagrams, in which are condensed the combined results of extensive and practical experiments.

By these it will be seen that we have spared no labor or expense to fully bring out the hidden and latent facts of experimental research.*

† LAWS AND PHENOMENA OF HEAT.

However various are the methods by which artificial heat is distributed in the warming of buildings, they are all reducible to certain rules, which constitute the primary laws of heat. These laws are very numerous, and some of them extremely complicated; but they possess a very high degree of philosophic interest. They are far too extensive, however, to allow in this work even a bare outline of the various phenomena to be given, which this branch of science exhibits. But in the present chapter, such of the laws of heat as relate to the subject more immediately before us shall be stated, in order to afford a more immediate and ready reference for those who wish to study the scientific principles of warming buildings by artificial heat. (See also diagrams Nos. 17 and 18.)

There are four distinct properties of heat, which all bodies possess in a greater or less degree, which we shall first consider. These are *radiation*, *absorption*, *conduction*, and *reflection*.

Heated bodies give off their caloric by two distinct modes — radiation and conduction. These are governed by different laws, but the rate of cooling by both methods increases considerably in proportion as the heated body is of greater temperature than the surrounding medium.

This variation was long supposed to be exactly proportional to the simple ratio of the excess of heat; that is to say, supposing any quantity of heat given off in a given time at a specified difference of temperature, at double that difference, twice the quantity of heat

* These may be summarized as follows: —
Ten cuts, direct radiating constructions.
Seven cuts, indirect radiating construction and appliances.
Eleven tables and diagrams illustrating conditions and results.

† Charles Hood.

would be given off in the same time. This law was originally proposed by Newton, in the *Principia;* and, although rejected as erroneous by some philosophers, it was followed by Richman, Kraft, Dalton, Leslie, and many others, and was usually considered to be nearly accurate until the masterly and elaborate experiments of Petit and Dulong proved that, although approximately correct for low temperatures, it becomes extremely inaccurate for the higher degrees of heat.

Heat may be conducted from any source to any material object in contact with it, whether solid, liquid, or gaseous.

When the generation of heat is continuous, there is a constant flow outwards and across the surfaces of the generator, which is maintained at a higher temperature than the bodies to which it contributes.

A hot body immersed in a gaseous medium, as the air, which completely envelopes it, is continually communicating its heat; the heat received makes the layer of air next to the surface lighter; this rises and gives place to air at a cooler temperature, thus establishing a current. This mode of the transfer of heat from a solid to a liquid is called *convection*, and is one of the most important factors in the transmission of heat for purposes of warming and ventilation.

The quantity of heat that is dispersed in this manner to the air is dependant on the area of the surface exposed to the cooling influences, and the temperature at which this surface is maintained. The conditions within the body are entirely immaterial, except as they permit or hinder the free flow of heat to maintain the surface temperature.

Thus the agent within the radiator may communicate its heat to the surface of the vessel containing it either by simple conduction, as in the case of *hot water*, or by the liberation of latent heat on the inside surface of the metal by the *condensation of steam;* the transfer of heat from the radiator to the air and other objects will not differ in either case, provided the conditions of the exterior surface are the same. In accordance with these principles, heating surface is usually estimated and sold by the square foot of external surface.

It may be stated that radiant heat is instantaneously transmitted through the air independently of any atmospheric currents intervening, and without sensibly warming the air. Therefore, in ordinary cases, air and gases cannot be warmed *directly* by radiant heat, except as they take up the heat by contact with solid bodies by which it has been already absorbed.

When the thickness of the air or gas is *very great*, it is evident that the air absorbs some of the heat that passes through it. This is shown in the case of the sun's rays, whose intensity is diminished at sunrise and sunset, when they pass by their oblique course through a layer of air *seven hundred and twenty-five miles thick*, nearly 14.5 times as great as when the sun is at the zenith.

The cooling of a heated body under the ordinary circumstances is evidently by the combined results of radiation and conduction.

The conductive power of the air is principally owing to the extreme mobility of its particles, for otherwise it is one of the worst conductors we are acquainted with; so that, when confined in such a manner as to prevent its freedom of motion, it is a most useful non-conductor.

The proportions that radiation and conduction bear to each other have, in general, been very erroneously estimated. Count Rumford considered the united effect, compared with radiation alone, was as five to three, and Franklin supposed it was five to two.

No such general law, however, can be deduced, for the relative proportions vary with the temperature and with the peculiar substance or surface of the heated body. For while the cooling effect of air by conduction is the same in all substances and in all states of the surface of such substances, radiation varies materially, according to the nature of the surface.

To show the relative velocities of cooling at different temperatures, the following table, constructed from the experiments of Petit and Dulong, is given. The first column shows the excess of temperature of the heated body above the surrounding air (at 32°); the second column shows the rate of cooling of a thermometer with plain bulb; and the third column gives the rate of cooling when the bulb was covered with silver leaf (thus suppressing the radiation); the fourth column shows the cooling due to the air alone; and, by deducting this from the second and third columns respectively, we shall find what is the amount of radiation under the two different states of the surface, noticed at the top of the columns.

TABLE No. 94.—THE VELOCITIES OF COOLING.

A.—Excess of Temp. of the Thermometer above that of the Air. Fahrenheit Scale.	Total Velocity of Cooling of the naked Bulb.	Total Velocity of Cooling of Bulb covered with Silver leaf.	Amount of Cooling due to Conduction of the Air alone.
468°	24.42	10.96	8.10
432	21.12	9.82	7.41
396	17.92	8.59	6.61
360	15.30	7.57	5.92
324	13.04	6.57	5.19
288	10.70	5.59	4.50
252	8.75	4.61	3.73
216	6.82	3.80	3.11
180	5.57	3.06	2.53
144	4.15	2.32	1.93
108	2.86	1.60	1.33
72	1.74	.96	.80
36	.77	.42	.34
18	.37	.19	.14

Some very remarkable effects may be observed by an inspection of the above table. It appears that the ratio of heat lost by contact of the air alone is constant at all temperatures; that is, whatever is the ratio between 40° and 80°, for instance, is also the ratio between 80° and 160° or between 100° and 200°.

Another remarkable law is, that the cooling effect of air is the same for the like excess of heat on all bodies, without regard to the particular state or nature of their surface.*

By comparing the second and third columns of the preceding table, it will be immediately perceived that the loss of heat by radiation (deducting the cooling by conduction to the air, given in the fourth column) varies greatly with the nature of the radiating surface; though, whatever be the nature of the surface, the loss of heat follows the same law in all cases, though in a different ratio.

It should be observed that in table A the second, third, and fourth columns show the number of degrees of heat which were lost per minute by the body which was the subject of the experiment, and therefore these numbers represent the velocity of cooling.

When the numbers in the last column are deducted from those in the second and third columns, the difference will show *the loss by radiation* for the plain and silvered bulbs respectively; the fourth column being *the loss by conduction to the air*, which is the same for all surfaces. It will immediately be perceived, therefore, that the losses of heat by conduction and by radiation bear no constant ratio to each other. But while conduction proceeds by a regular geometrical progression, radiation follows another law.

It will likewise appear that, when we compare the total cooling of two surfaces, the law is more rapid at low temperatures, and less rapid at high temperatures, for the body that radiates the least, in comparison with that which radiates with greater power.

But the cooling of a body by conduction of the air differs from the effect by radiation in a remarkable manner, in this particular — that, while the ratio of loss by conduction continues the same for the same excess of temperature, whatever be the temperatures of the air and the heated body, radiation increases in velocity, for a like excess of temperature, when the temperatures of the air and heated body increase.

To revert to table B, we find the total cooling at 108° and 216° (of Fahrenheit) to be about as 3 to 7; at 108° and 292° as 3 to 13; and at 108° and 432° as 3 to 21; whereas, according to the old theory of Newton, they should have been respectively as 3 to 6; as 3 to 9; and as 3 to 12. But we find that the deviation increases greatly with the increase in temperature, and that when the excess of temperature of the heated body above the surrounding air is as high as 432° Fahr., the real velocity of cooling is nearly double what it would appear to be by the old and imperfect theory.

---

* This is true as regards differences of material and the character of the surface as to roughness. The form of the surface makes a considerable difference, by determining the movements of the air when heated; a square foot of one-inch pipe, for example, losing double the heat in a given time to the air of a square foot of six-inch pipe. See table No. 9.

The following table shows the velocity of cooling by radiation for the same body at different temperatures.

It will be observed in this table that, when the absolute temperatures of the surrounding medium and radiating body are increased 45° Fahr., the difference between their temperatures remaining the same, the velocity of cooling is multiplied by 1.165, which is the mean of all the ratios in the table experimentally determined.

B.—Excess of Temperature of the Thermometer.	**Velocity of Cooling when the surrounding medium is at the under-mentioned Temperatures (Fahr.)**			
	32°	**68°**	**104°**	**140°**
396°	8.81	10.41	11.98	
360	7.40	8.58	10.01	11.64
324	6.10	7.04	8.20	9.55
288	4.89	5.67	6.61	7.68
252	3.88	4.57	5.32	6.14
216	3.02	3.56	4.15	4.84
180	2.30	2.74	3.16	3.68

But radiant heat is subject to other laws besides those we have yet considered. Rays of heat diverge in straight lines from every part of a heated surface, and likewise from extremely minute depths below the surface of hot bodies, being subject to the laws of refraction the same as light. The intensity of these rays decreases as the square of the distance, and the emission of rays is greatest in a line perpendicular to the surface. The same law obtains here also as in the case of light — that the effect of the ray is as the sine of the angle which it forms with the surface from which it emanates.

This law of sines, first discovered experimentally by Leslie, suggests a practical caution connected with the subject before us; namely, that the shape of the pipes used to warm a building is not wholly unimportant; for if flat pipes be used, and they be laid horizontally, the majór part of the radiated heat from the upper surface will be received on the ceiling, and therefore will produce but little beneficial effect. The loss sustained in this way will be greater in proportion to the higher temperature of the pipes; for it will be seen by the table at the beginning of this chapter that the relative proportion which radiation bears to conduction increases with the temperature; at the ordinary temperature of hot-water pipes, about one half of the total cooling is due to radiation.*

It is very generally supposed that color has a considerable influence on radiant heat, and also upon the absorption of heat, the two effects being similar and equal. Sir Humphry Davy, by exposing surfaces of different colors to the heat of the sun, proved experimentally that the absorbing power of different colors was in this order: black, blue, green,

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*NOTE. — The *radiation* of heat, we have already seen, is very greatly increased or diminished according to the state of the surface of the radiating body. See table No. 8½.

red, yellow, and white; black being the best and white the worst absorbent. In this order, then, we should expect to find the radiating powers of different colors, and that by painting a body a black color we should increase its powers of radiation. This, however, is not the case; and there are the strongest reasons for supposing that the absorption and radiation of *simple heat*—that is, *heat without light*, or heat from bodies below luminosity—are wholly irrespective of color, and depend upon the nature of the surface.

By comparing the results given (by Leslie), it will appear that the radiation of heat bears no relation to color when the radiating body is below the temperature of boiling water. By this it also appears that lamp-black and white paper are nearly equal in power; while India ink is much less, and black lead still lower in the scale; though as far as color is concerned these last are nearly the same as lamp-black. Professor Powell considers, as also did Leslie, that softness may tend to increase the radiation of simple heat; and the former found that a thermometer bulb coated with a paste of chalk was affected by this kind of heat, that is, by heat below luminosity, even more than a similar one coated with India ink; but the same result does not occur in luminous hot bodies. Professor Bache has likewise made an extensive series of experiments on this subject which confirm this result.

[*] For ordinary temperatures of absorbing surfaces, say 50° to 60°, and small differences between the surface and the walls, say 30°, we may admit that the loss of heat is simply proportional to that difference; but for high temperatures of the surface and great differences between the temperature of absorbent and radiator, the loss of heat is much greater following a complicated law, for which Dulong has given a rule that agrees well with experiment up to a very high temperature.

The radiation of heat is not affected by the form of the radiating body. A cube, a sphere, a cylinder, etc., will radiate the same amount of heat for equal areas under the same conditions, *so long as the body is not of a form to radiate to and from itself.* (See diagrams Nos. 17 and 18.)

The radiation of heat is not affected by the distance of the absorbent. Thus, if the space traversed were a vacuum, it would be quite immaterial whether the walls were inches or miles distant from the radiating surface; the rays of heat would travel on until they were absorbed by the cold body that had attracted them. Thus the heat that we receive from the sun is radiant heat that has traveled ninety-five millions of miles through space.

Radiant heat has the remarkable property of passing through moderate thicknesses of air or gas without appreciable loss, or heating the air sensibly; *so that in ordinary cases we may admit that air and gases cannot be heated directly by radiant heat, but only by contact with heated bodies.* With very great thicknesses, however, such as several miles, the loss of heat becomes manifest, as is shown by the diminished power of the sun at and near its rising and setting, when its rays, passing very obliquely through the atmosphere, traverse a much greater thickness of air than at midday.

The loss of heat by contact of cold air is independent of the nature of the surface, so that cast iron, stone, wood, etc., etc., would lose the same amount of heat, under the same conditions of temperature; *but the form of the body affects the result considerably, so that a plane, a sphere, and a cylinder will lose different amounts of heat per square foot in the same time.*

[*] Thos. Box.

The experiments of Leslie proved that radiation proceeds, not only from the surface of bodies, but also from small depths below their surfaces; and therefore the thickness of the coating of any good radiating substance materially affects the results.

We are fully justified, then, by these and analogous experiments, in drawing the conclusion that the radiation of simple heat is not influenced by the color of the heated body.

The effect of roughness of the surface was illustrated by Sir J. Leslie, and he found that either tarnished surfaces, or such as are roughened by emery, by the file, or by drawing streaks and lines with a graving tool, always had their power of radiation considerably increased.

The accuracy of this deduction had not been questioned until some recent experiments of M. Melloni, by which it has been ascertained that this increased effect from roughened surfaces is not a general law, but is only a particular result, for which another explanation must be sought. M. Melloni experimented with four plates of silver, two of which, when cast, were left in their natural state without hammering, and the other two were planished to a high degree under the hammer. All the plates were then finely polished with pumice stone and charcoal; but, after this, one of each of the pairs of plates was roughened by rubbing with coarse emery paper in one direction.

The quantity of heat radiated from these plates was as follows: —

Hammered and polished plate	10
Hammered and roughened plate	18
Cast and polished plate	13.7
Cast and roughened plate	11.3

In comparing these effects, it appeared that the hard hammered plate increased in radiating power four fifths by *roughening its surface*, while the soft cast plate lost nearly one fifth of its power by the same process. M. Melloni therefore draws the conclusion that the roughness of the surface merely acts by altering the superficial density, and that this will vary according as the body is of a greater or less density previous to the alteration in its surface by roughening.

It was deduced from experiments by Leslie that the absorptive power of bodies for heat was nearly proportional to the radiating power; and Dr. Ritchie has since proved that these effects are precisely equal to each other.

It has also been established by the experiments of MM. Melloni and Nobili that the radiating powers of surfaces for simple heat are in the inverse order of their conducting powers.

We might be led to conclude, from all that precedes, that those metals which are the worst conductors would be the most proper for vessels or pipes for radiating heat; because we find that heat, lost by contact with the air, is the same for all bodies, while those which radiate most or are the worst conductors give out more heat in the same time than those bodies which radiate least or are good conductors. Such would be the case, if the vessels were infinitely thin; but, as this is not possible, the slow conducting power of the metal opposes an insuperable obstacle to the rapid cooling of any liquid contained within it, by preventing the exterior surface from reaching so high a temperature as would that of a more perfectly conducting metal under similar circumstances, thus preventing the loss of heat, both by contact of the air and radiation, the effect being proportional to the excess of heat of the exterior surface of the heated body.

SPECIFIC HEAT.

Different bodies require very different quantities of heat to effect in them the same change of temperature. The capacity of a body for heat is called its specific heat, and may be defined as the number of units of heat necessary to raise the temperature of one pound of that body 1° Fahr. Table No. 8½, (B) gives its value for most of the solid and liquid bodies met in practice, and also for the most common gases, and shows that it is very variable. For instance, mercury requires only about one thirtieth of the heat necessary for the same weight of water. This table illustrates the important fact that of all substances *water has the greatest specific heat; that is to say, it absorbs more heat in warming, and gives out more in cooling through a given range of temperature than an equal weight of any other substance.* The quantity of heat which raises a pound of water from 32° to 212° Fahr. would suffice to raise a pound of iron from 32° to about 1,580° Fahr.; that is, to a red heat; and, conversely, a pound of water cooling from 212° to 32° gives out as much heat as a pound of iron in cooling from 1,580° to 32°. It will be further noticed, on examination of this table, that the specific heat of the metals is very small, indicating that a very small amount of heat is required to raise their temperature.

When the specific heat of a body and also its weight is known (Table 8½ A), it is easy to compute how many units of heat are required to raise the temperature any number of degrees. For instance, ten pounds of iron are raised 100° in temperature, and the specific heat of iron is .114. To raise ten pounds of iron 1° would require 1.14 units of heat; 100° would require 114 units.

The above property of water is utilized wherever it is desired to store large quantities of heat, without increasing the temperature or tension of the heat in the body, and thus causing its rapid dissipation (the loss by conduction and radiation increasing with the temperature).

An example on a large scale is furnished by nature in the ocean current flowing from the Gulf of Mexico northward along the Atlantic coast, and from thence across to England. A great amount of heat absorbed in the tropics is retained throughout the whole course of the stream, and serves to modify the climate of the British Isles and the eastern States of America.

The following table, No. 8½, A, B, C, and D, is taken from Box, with slight changes. Table No. 9 and diagram No. 16 are arranged to further illustrate the transfer of heat by contact of air and radiation.

TABLE No. 8½.

WEIGHT OF MATERIALS AND THEIR RELATIVE POWERS OF ABSORBING AND TRANSMITTING HEAT.

(A) Specific Gravity

Ratio of Weight of Material to the Weight of an Equal Volume of Distilled Water. (Pg. 51, Box.)

	Spec. Grav.	Wt. of Cu. Ft.	No. of Cu. Ft. in 1 Ton.
Mercury,	13.596	847.3	2.644
Lead,	11.352	707.5	3.166
Copper, sheet,	8.785	547.5	4.091
Gun Metal, cast,	8.670	540.3	4.145
Copper, cast,	8.607	536.4	4.176
Brass, cast,	8.393	523.1	4.282
Wrought Iron,	7.788	485.3	4.615
Tin, cast,	7.291	454.4	4.930
Zinc, sheet,	7.190	448.1	4.999
Cast Iron, mean,	7.087	441.6	5.07
Zinc, cast,	6.861	427.6	5.24
Slate,	2.835	176.7	12.68
Glass,	2.760	172.0	13.02
Granite,	2.662	165.9	13.50
Sandstone,	2.506	156.2	14 34
Brick,	1.841	114.7	19.52
Sand, river,	1.546	96.35	23.25
Coal, mean,	1.313	81.83	27.37
Water, distilled,	1.000	62.32	35.95
Ice at 32°,	.93	57.96	38.65
Alcohol,	.813	50.67	44.21
Oil, olive,	.9153	57.04	39.27
Oak, seasoned,	.777	48.42	46.26
Elm, seasoned,	.588	36.65	61.13
Mahogany, seasoned,	.560	34.9	64.18
Pine, yellow, seasoned,	.483	30.1	74.41
Coke, gas, in measure,	.353	22.0	101.8
Cork,	.24	14 96	149.7

(B) Specific Heat

= Units of Heat required to Raise the Temperature of One Pound One Degree. (Pg. 2, Box.)

METALS.		EARTHS, Etc.	
Cast Iron,	.130	Ice,	.504
Wrought Iron,	.114	Beeswax,	.450
Zinc,	.096	Spermaceti,	.320
Copper,	.095	Coal,	.278
Brass,	.094	Marble,	.216
Silver,	.057	Chalk,	.215
Tin,	.057	Sulphur,	.203
Mercury,	.033	Coke,	.201
Gold,	.032	Glass,	.198
Platina,	.032	Burnt Clay,	.185
Lead,	.031		
Bismuth,	.031		

LIQUIDS.

Water at 32°,	1.000
Alcohol, sp. gr. .793,	.622
Ether, sulphuric,	.477
Oil of Turpentine,	.472
Petroleum,	.434
Olive Oil,	.310

WOODS.

Pine,	.650
Oak,	.570
Birch,	.480

GASES AT CONSTANT PRESSURE.

Atmospheric Air,	.238
Vapor of Water,	475

(C) Radiating and Absorbing Power

= Units of Heat per Sq. Ft. per. Hour for 1° Diff. in Temp. between Radiator and Receiver. (Box, Pg. 203.)

Silver, polished,	.027
Copper, polished,	.033
Tin, polished,	.044
Zinc and Brass, polished,	.049
Tinned Iron, polished,	.086
Iron, sheet, polished,	.092
Lead, sheet,	.133
Iron, sheet, ordinary,	.566
Glass,	.595
Cast Iron, new,	.648
Chalk,	.679
Cast and Sheet Iron, rusted,	.687
Wood Sawdust, fine,	.721
Building Stone, Plaster, Wood, Brick,	.736
Sand, fine,	.740
Calico,	.746
Woolen Stuffs, any color,	.752
Silk Stuffs, Oil Paint,	.758
Paper, any color,	.771
Lamp-black,	.820
Water,	1.085
Oil,	1.480

(D) Conducting Power

= Units of Heat per Sq. Ft. per Hour per Deg. Diff. in Temp. of Surfaces of Plate 1 In. Thick. (Pg. 211, Box.)

Copper,	515.
Iron,	233.
Zinc,	225.
Lead,	113.
Marble, gray, fine-grained,	28.
Marble, white, coarse-grained,	22.4
Stone, calcareous, fine,	16.7
Stone, calcareous, ordinary,	13.68
Glass,	6.6
Baked Clay, brick-work,	4.83
Plaster, ordinary,	3.86
Oak, transm'sion perpendic'lar to fibres,	1.70
Walnut, " " "	.83
Fir, " " "	.748
Fir, transmission parallel to fibres,	1.37
Walnut, " " "	1.40
India-rubber,	1.37
Cork,	1.15
Wood Ashes,	.531
Canvas of Hemp, new,	.418
Calico, new,	.402
White Writing-paper,	.346
Cotton and Sheep Wool (any density),	.323
Blotting-paper, gray,	.274

TABLE No. 9.

SHOWING THE HEAT LOST OR TRANSMITTED FROM STEAM AND HOT WATER HORIZONTAL PIPES OF DIFFERENT DIAMETERS, AND AT DIFFERENT TEMPERATURES.

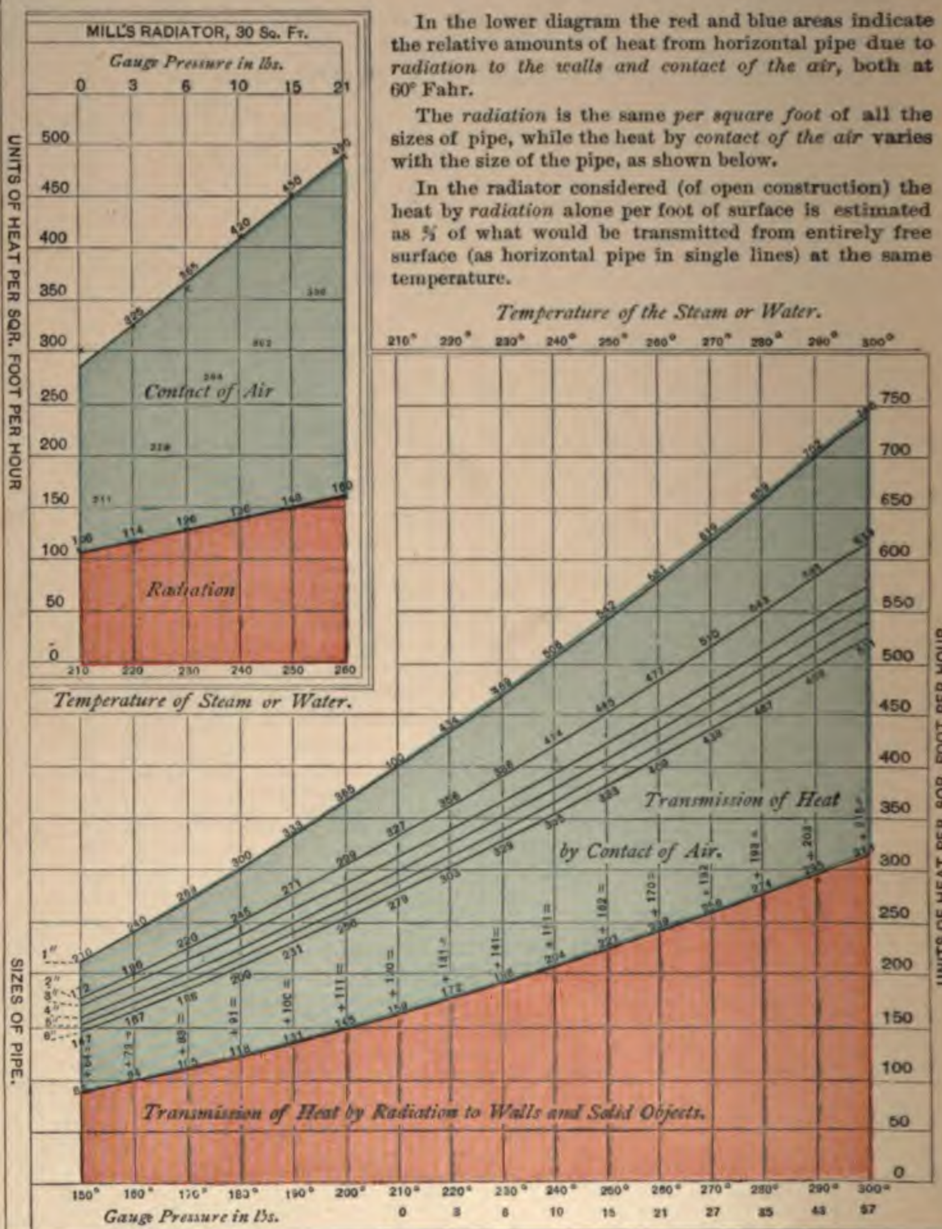
Gauge Pressure per Square Inch.	TEMPERATURES.				1 IN. PIPE. Units of Heat per Square Foot per Hour.				2 IN. PIPE. Units of Heat per Square Foot per Hour.				3 IN. PIPE. Units of Heat per Square Foot per Hour.				4 IN. PIPE. Units of Heat per Square Foot per Hour.				5 IN. PIPE. Units of Heat per Square Foot per Hour.				6 IN. PIPE. Units of Heat per Square Foot per Hour.			
	Steam or Water.	Air of Room.	Walls of Room.	Difference Temperature, Air and Steam or Water.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.	Radiation to Walls of Room.	Conduction to Air of Room.	Total Heat.	Per Degree Difference Pipe and Air.
52	300	70	60	230	316	407	723	3.14	316	286	602	2.62	316	245	561	2.44	316	225	541	2.35	316	215	531	2.31	316	203	519	2.26
43	290	"	"	220	295	385	680	3.09	295	269	564	2.56	295	231	526	2.39	295	212	507	2.30	295	202	497	2.26	295	193	488	2.22
34	280	"	"	210	274	363	637	3.03	274	254	528	2.51	274	218	492	2.34	274	201	475	2.26	274	191	465	2.22	274	182	456	2.17
27	270	"	"	200	256	342	598	2.99	256	238	494	2.47	256	204	460	2.30	256	188	444	2.22	256	180	436	2.18	256	171	427	2.13
21	260	"	"	190	239	321	560	2.95	238	224	462	2.43	239	193	432	2.27	239	177	416	2.19	239	170	409	2.15	239	161	400	2.10
15	250	"	"	180	221	301	522	2.90	221	210	431	2.39	221	181	402	2.23	221	166	387	2.15	221	159	380	2.11	221	151	372	2.07
10	240	"	"	170	204	281	485	2.85	204	197	401	2.37	204	170	374	2.20	204	156	360	2.12	204	148	352	2.07	204	141	345	2.03
6	230	"	"	160	188	261	449	2.80	188	184	372	2.33	188	158	346	2.16	188	145	333	2.08	188	138	326	2.03	188	131	319	1.99
2	220	"	"	150	172	241	413	2.75	172	169	341	2.29	173	145	318	2.12	173	133	306	2.04	172	127	299	1.99	172	120	292	1.95
0	210	"	"	140	159	220	379	2.71	159	154	313	2.24	159	132	291	2.08	159	121	280	2.00	159	116	275	1.96	159	110	269	1.92
	200	"	"	130	145	201	346	2.66	145	140	285	2.19	145	120	265	2.04	145	110	255	1.96	145	106	251	1.93	145	100	245	1.89
	190	"	"	120	131	182	313	2.61	131	127	258	2.15	131	109	240	2.00	132	100	232	1.93	131	96	227	1.90	131	91	222	1.85
	180	"	"	110	118	164	282	2.56	118	114	232	2.11	118	99	217	1.97	118	91	209	1.89	118	86	204	1.86	118	82	200	1.81
	170	"	"	100	105	146	251	2.51	105	102	207	2.07	106	87	193	1.93	106	80	186	1.86	105	77	182	1.82	105	73	178	1.78
	160	"	"	90	94	127	221	2.46	94	89	183	2.03	94	76	170	1.89	94	70	164	1.83	94	67	161	1.79	94	64	158	1.75
	150	"	"	80	83	109	192	2.40	83	77	160	2.00	83	66	149	1.86	83	61	144	1.80	83	58	141	1.76	83	55	138	1.73

DIAGRAM No. 16.

Transmission of Heat by Contact of Air and Radiation.

Per Sq. Foot of Surface of Horizontal Pipes 1, 2, 3, 4, 5, 6 in. diam., and by Direct Radiators. Results of Theory and Experiment.

SEE TABLE No. 9, AND DIAGRAMS AND CHAPTER ON RADIANT HEAT.



In the lower diagram the red and blue areas indicate the relative amounts of heat from horizontal pipe due to *radiation to the walls and contact of the air,* both at 60° Fahr.

The *radiation* is the same *per square foot* of all the sizes of pipe, while the heat by *contact of the air* varies with the size of the pipe, as shown below.

In the radiator considered (of open construction) the heat by *radiation* alone per foot of surface is estimated as ⅗ of what would be transmitted from entirely free surface (as horizontal pipe in single lines) at the same temperature.

CHAPTER XVIII.

VARIOUS MATERIALS AND FORMS AS RADIATORS.

THE foregoing and brief resumé of some of the laws of heat is confined, as seen, to the matter of the transfer of heat from hot bodies and materials, as iron and other metals employed in radiators to warm rooms, and to the method by which such surfaces surrender this internally supplied heat to the air and solid objects, the walls, etc.

The authorities cited are numerous, their method of deducing the facts illustrated, while the successive steps, so clearly shown by the tables, leave no doubt that their conclusions as to the functions of heating and radiating surfaces are correct.

As, however, this matter of the passage of heat from warm pipe surfaces to cooler ones is of the first moment when we begin later to consider the construction of radiators, we introduced a carefully prepared table from the formulas as given by Box and Hood and Peclet, showing the entire operation of heat transfer for all the ranges of temperatures employed in heating, and for sizes of pipes and tubes of one inch to six inches in diameter, also diagram No. 16, graphically illustrating the two methods by which heat is surrendered both by pipe surfaces and also by radiators.

See also following diagrams Nos. 17 and 18.

The especial use of this table and diagrams will be seen later, when we again take up the subject of radiant heat in connection with the construction of radiators and other heating surfaces.

There will be noticed a slight difference between the figures in the table and those shown on diagram No. 16; this is due to the fact that in the table the air is taken at 70° and walls of the room at 60° (our average heating condition), while in the diagram the figures are for both walls and air at 60°, and thus the total heat is a little greater than in the table. Attention is drawn to the fact that each size of pipe has a duty pertaining to its size, which decreases as the pipe increases in diameter; also, that should two lines be placed near each other and tested at the same time, the combined effect would be less, and would continue to decrease as the number of lines became greater.

The heat by *contact of the air*, unlike that by radiation, is influenced by the form of the surface, which affects its access to the cooler air, and unobstructed passage of the air when heated. Thus in diagram No. 16, the *radiation* (indicated by the color red) is the same for pipes one, two, three, four, five, and six inches in diameter; the heat by conduction (blue) varies for each pipe, being for one-inch pipe at 300° 430 units.

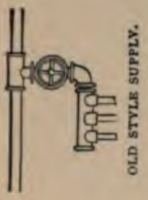
Again, this is the heat given out by *horizontal* pipes; if now the pipes were vertical, the heat surrendered under the same conditions would be less, and continue to decrease as the pipes were multiplied in number.

That wrought iron in tubes of small diameters, say ¾ to 1½ inch, is not exceeded in heating power by any other material or form of surfaces, may be at once conceded; and for facility of comparison we will take the value of 1-inch pipe in a single horizontal line, as found by Joseph Nason, 1862, to be 447 units of heat given off per square foot per hour for the standard condition; viz., steam at 5 pounds (or 228°) and air at 70°. If now we find it desirable to use several lines of pipes, say in a 3 or 4 branch circulation, we shall not be able to realize as much heat, due to the radiating of the several pipes to and from each other and the less freedom of the air in reaching the entire surfaces. Our product of condensation represents now but 400 units instead of 447. See table No. 10, experiment No. 16.

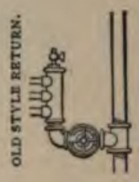
The further use of wrought-iron pipe is seen in the return bend box coil, plate No. 26, figure 4. In this shape we get a still lower efficiency, and we read for 60 feet surface 340 units per foot per hour for standard conditions. This is from a coil 10 pipes high, 6 wide, and 39 inches long. This occupies more than double the room that would be taken up by a radiator having the same amount of heating surface, while it is anything but ornamental, and is generally covered by a screen which, although increasing the cost, farther decreases the efficiency. So that there seems to be no good reason for employing pipe in this form to obtain heating surface.

Plate No. 24 shows the latest and best arrangement of wrought-pipe circulation, including the patent manifold and valve, which, while reducing the number of joints, renders the employment of a pipe circulation more satisfactory, and places the lines under better control, as by the use of these manifolds one or two lines may be closed, while the other surface continues in operation. This is not practicable with the old branch, with the headers shown at the right and left of the page at the top. This improved valve also admits of ready removal and repair, not possible with the old arrangement. Coils so arranged make the best heating surface to place below the windows in school-rooms, and may be used with either a steam or water circulation. See diagram No. 16 and table No. 9.

PLATE NO. 24.

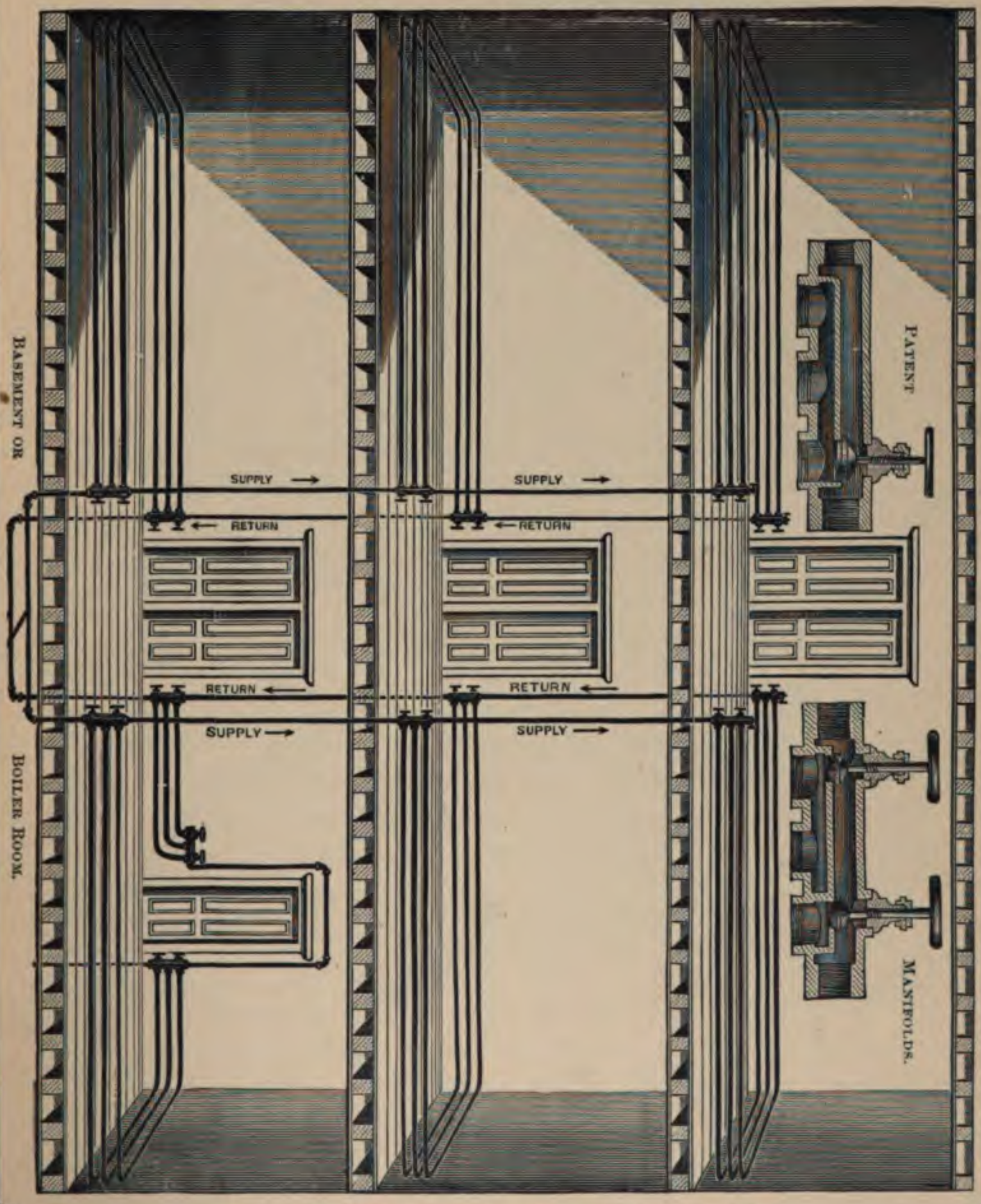


IMPROVED MANIFOLD AND VALVE



For Pipe Circulations and Coils.

MAY BE USED IN EITHER STEAM OR WATER HEATING.



C. C. Walworth's Patent. See also Diagram 31 (School Heating).

Until within a few years the box coil was often employed as indirect surface for steam circulation below the floors, and with an outdoor supply of cold air; but the difficulty of bringing the air in actual contact, even when the pipes were staggered, has led to the practical abandonment of box coils for this particular work. We will look at this relation further, when considering indirect heating.

In plates Nos. 25 and 26, we see the regular vertical tube radiators in one row, two or three rows wide, and on plate No. 26, a horizontal one in staggered tube *indirect* radiator, compared with the return bend box coil; this last heating the air as hot as the box coil at five times its height, and also with less pipe.

Plate No. 25 shows a very efficient wrought-pipe radiator, made of 1¼ inch tubes, let into special bases. The freedom of the air to reach every inch of the surface and the perfect display of the surfaces to discharge radiant heat render this simple construction one of the best that the writer has ever seen. That this surface is above the 350 units credited to it, may be seen from the proportion of space heated with a *water circulation*, this being 1 to 90 cubic feet of space, with a large glass exposure. See table No. 17.

Plate No. 27 shows circular radiators of both wrought and cast-iron tubes, also a special arrangement for the introduction of pure outside air. Under these conditions, the efficiency of circular radiators may be taken as *four hundred units*, or equal to that of a 4-branch circulation.

Returning now to the efficiency and value of wrought vertical pipe radiators, we find that the *single-row* radiator of regular heights and solid bases is about equal in value to four-branch circulation; the average of seven experiments by J. J. Nason and J. H. Mills give (standard steam and air, difference 158°) 390 units per square foot per hour. For *two-rowed* vertical radiators, four experiments by Nason, Barrus, and Mills give 309 units. (Table No. 11.)

With three rows of tubes wide the mean of five tests by the writer gives 278 units per foot, and thus the respective values decrease in the ratios of 390, 309, 278; the two rows being one fifth, and the three rows three tenths, less than the one row.

For cast-iron vertical tube radiators an average of twenty tests made by the Griffing Iron Company with 1, 2, and 3 rows of tubes gave 395, 315, and 275 units as the respective duty of the several radiators.

The following table (No. 10) gives several additional examples of different materials, and also different conditions of the same pipes described as *corrugated*, *ringed*, and *plain surfaces*. The table also shows the efficiency for many radiators not found in table No. 11.

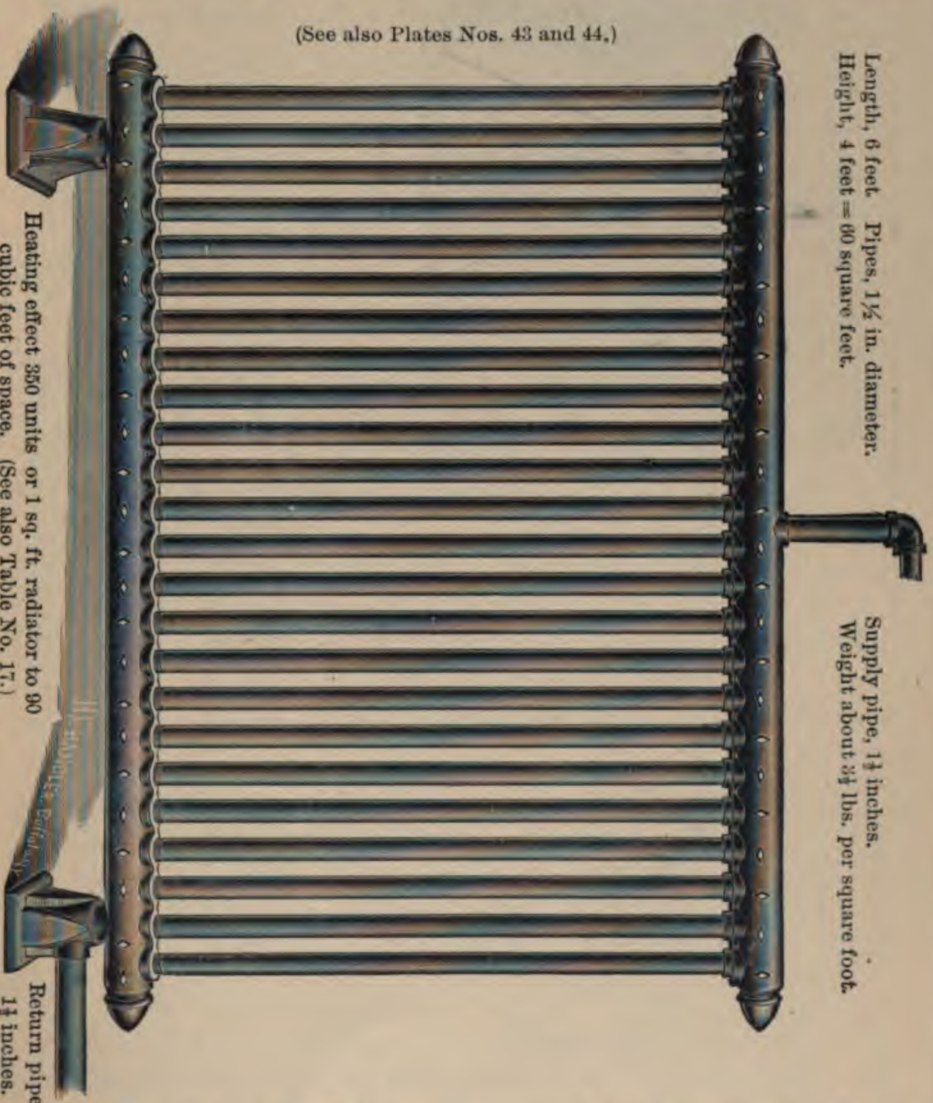
As most of these surfaces are familiar to the trade of heating engineers of the Eastern and Middle States, no lengthy description of the nature of the surface is attempted.

PLATE NO. 25.

SPECIAL WROUGHT-IRON DIRECT RADIATOR.

Employed for Water Circulation at County Buildings, Springfield, Mass., 1887.

(See also Plates Nos. 43 and 44.)



Length, 6 feet. Pipes, 1½ in. diameter.
Height, 4 feet = 60 square feet.

Supply pipe, 1¼ inches.
Weight about 3¼ lbs. per square foot.

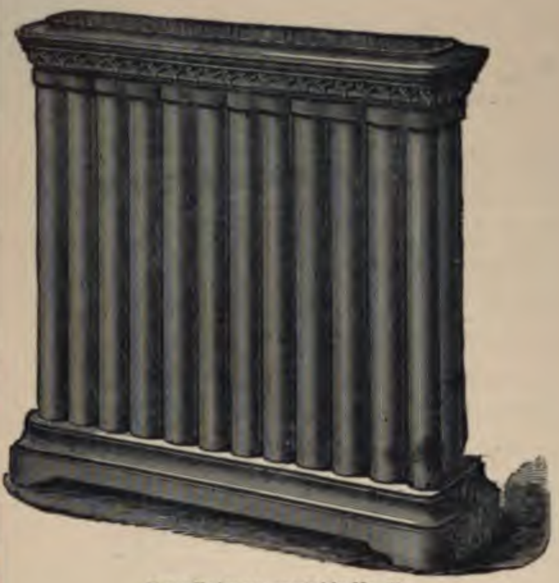
Heating effect 350 units or 1 sq. ft. radiator to 90 cubic feet of space. (See also Table No. 17.)

Return pipe 1¼ inches.

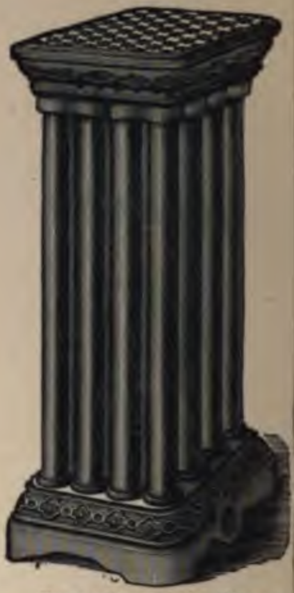
This Wrought-Iron Pipe Radiator was constructed with straight thread and lock nut at top for special public work, as Prison, Asylum, and Hospital heating, it being high from the floor and without *base*, *screen*, *movable* or *loose parts*.

WROUGHT IRON DIRECT AND INDIRECT RADIATORS.

PLATE NO. 26.

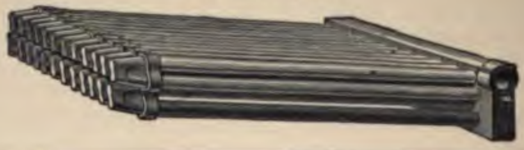


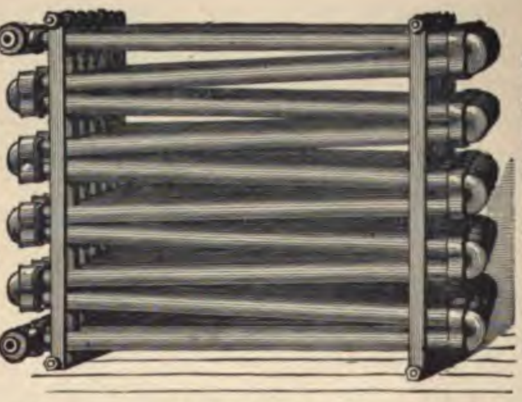
For efficiency, see table No. 11.



For sections of the above see diagram No. 17, page 336.

INDIRECT RADIATOR.
C. C. W. Pats.





For efficiency, see table No. 13.

For section of box coil, see plate 36, page 359.

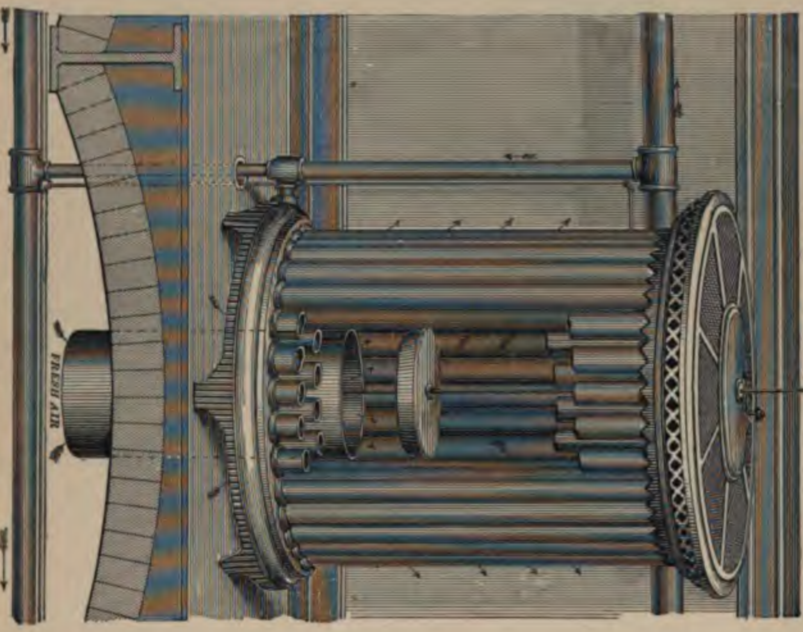
REGULAR RETURN BEND BOX COIL.

PLATE NO. 27.

CIRCULAR RADIATORS OF WROUGHT AND CAST IRON TUBES.

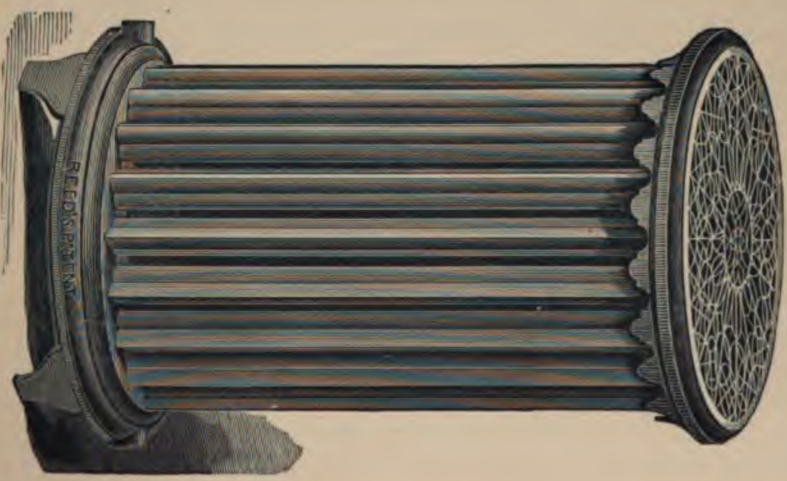
* See Report of Providence Steam and Gas Pipe Co., 1884.

Mills Overhead Supply Piping and Single Connection to Radiators.
1873 – 1874.



* Heating and Ventilation, Cranston Prison, R. I., 1884.
Walworth Radiators in Corridors, 44 = 4,400 square feet.

Circular Cast Iron Column Radiator.



The H. B. Smith Co.,
Westfield, Mass.

Before passing to the matter of construction of any radiator, it seems best to consider the question of materials, since more or less difference of opinion has existed as to the heating values of *wrought-iron, steel, brass, and cast-iron pipes, when employed as direct radiators.*

The people really interested in the intrinsic merits of radiating surfaces are not only the manufacturers, but the contractor and the heating engineer; as, having made calculations on the asserted square feet and the supposed value, if this fall short in actual use, he must make good the deficiency, and often at serious loss.

If instead of iron a different material is employed in constructing a radiator, the amount of heat radiated will not be as great. More especially if the surface is highly polished, the radiation is diminished.

Taking cast iron as the standard, the radiating power of wrought iron, with its surface in the condition of rolled sheet, will be, theoretically, 10 per cent less. *Practically there seems little difference.*

If an iron radiator were finely polished, or had its surface brightly tinned or nickel-plated, five sixths of the heat by radiation would be suppressed; and if of polished brass or copper, the *radiation* is only about one sixteenth to one twentieth of that obtained from unpolished iron.

Tredgold made some experiments on iron in different states and on glass; a condensed summary runs as follows:—

Vertical cylinders, 8″ high by 3″ in diameter (nearly). Water at a mean temperature of 165°, air 56°, difference 109°. Units of heat per square foot of surface per hour: Tinned iron, 161; glass, 250; wrought iron, 252; same, rusted, 290.

More extended and practical tests with different materials and forms employed, as both direct and indirect heaters, are shown in table No. 10. These were made, as seen, by that early and practical engineer, Joseph Nason, in 1862, and by the writer in 1888, and with table No. 11 comprise about all the data we have to offer.

Tests were made with these radiators heated by steam, pressures and temperatures given in columns B and C. The amount of water condensed from the steam is taken as the measure of the heat given out by the radiators (column F); one pound of condensed steam, at an assumed temperature, when leaving the radiator, at 180° being equivalent to 1,000 units of heat. Column G gives the amount of heat due to one square foot of radiating surface per hour under the conditions of the test. Column H is the proportional amount of heat for 1° difference between the temperatures of the steam within the radiator and the air outside; and this multiplied by 158, the difference in temperature between steam at five pounds pressure (temperature 228°) and air of the room at 70°, shows the heating effect for each radiator *corrected for uniform conditions in the temperature of the steam and air.*

TABLE No. 10.

Miscellaneous and Final Experiments on Different Steam-Heated Surfaces and Different Materials:

WROUGHT IRON, CAST IRON, STEEL, and BRASS PIPES; CORRUGATED, RINGED, and PLAIN Surfaces.

No. for Reference.		DESCRIPTION OF HEATING SURFACE.	Sq. Ft. of Surface.	TEMPERATURES.			Lbs. of Metal per Sq. Ft. of Surface.	Ounces of Water Condensed per Sq. Ft. per Hour.	Lbs. of Metal Required to Condense 1 lb. of Water per Hour. E×1000÷H.	Units of Heat per Sq. Ft. per Hour.			
				Steam.	Air of Room.	Difference B – C.				Recovered F×62.5	Per Degree Diff. Steam and Air. H÷D.	Est. for Air 70°, Steam 228°. I×158.	
			A	B	C	D	E	F	G	H	I	J	
1	J. H. NASON, 1862.	Plain Wrought Iron Pipe, 1″, 100′ in a single horizontal line..............	33.30	212	70	142	5.28	6.56	12.9	410	2.89	447	
2		„ Cast „ „ 3″ diameter outside, 5′ long....................	4.02	212	70	142	8.70	5.50	25.6	344	2.42	382	314
3		„ „ „ „ 3″ „ „ 5′ „ but thinner than above	4.02	212	70	142	6.40	5.50	18.6	344	2.42	382	
4		Ribbed Cast Iron Pipe, S. Williams; core 3″ diam., 5′ long; ribs ⅜′ deep, ½″	8.87	212	70	142	5.30	3.84	22.1	240	1.69	267	
5		„ „ „ „ No. 1, J. Nason & Co., 3″ outside. [bet. c't'rs, 1″ c't'rs.	10.70	212	70	142	5.90	4.40	21.5	275	1.95	308	
6		„ „ „ „ „ 2, „ „ 3″ „ heavier ribs than No. 1.	9.20	212	70	142	6.80	4.49	24.2	281	1.98	313	
7		Plain Cast Iron Pipe, J. Nason & Co. } Placed side by side and tested together {	4.02	212	70	142	8.70	5.76	24.3	360	2.54	401	
8		Ribbed „ „ „ „ „	10.70	212	70	142	5.90	3.92	24.2	245	1.72	272	
9		Curved Rib Cast Iron Radiator, Morris, Tasker & Co.....................	14.14	212	70	142	7.10	4.30	26.4	269	1.89	299	
10		Box Radiator, cast iron, with straight vertical ribs	44.30	212	70	142	8.10	3.63	35.7	227	1.60	253	
11		Vertical Cast Iron Ringed Pipe Radiator, 7 sections, "Clogston".	21.00	212	70	142	8.20	3.80	34.6	237	1.67	264	
12	J. H. MILLS, 1888.	**Cast Iron** Pipe, 3″ diameter, in single line................................	25.00	222	70	152	......	5.00	......	313	2.06	325	311
13		**Wrought** „ 3″ „ „ „ „	26.00	228	70	158	......	5.00	.....	313	1.98	313	
14		**Steel** Pipe, 4″ „ „ „ „	25.00	230	68	162	......	4.95	......	309	1.86	294	
15		**Brass** 1″ Horizontal Pipe; 4 branch circulation	10.00	230	62	168	......	5.62	......	351	2.09	330	
16		Wrought Iron, 1″ Horizontal Pipe; 4 branch circulation..................	10.00	228	65	163	......	6.60	......	413	2.53	400	
17		Plain Brass Vertical Tube Radiator, 1½″ diam., 2×4	12.00	230	62	168	......	4.30	......	269	1.60	253	328
18		Corrugated Brass „ „ 1½″ „ 2×16	48.00	228	60	168	......	3.39	......	212	1.26	199	
19		Vertical Wrought Iron Tube Radiator, Walworth, 1 row of 20 pipes........	20.00	228	77	151	......	5.87	......	367	2.43	384	330
20		„ „ „ „ „ „ 2 „ 16 „	32.00	228	70	158	......	5.49	......	343	2.04	322	
21		„ „ „ „ „ „ 3 „ 16 „	48.00	228	72	156	......	4.50	......	281	1.80	284	
22		"Union" Radiator, cast iron, 6 sections, 29″ high..........................	25.00	228	70	158	......	5.12	......	320	2.03	320	335
23		"Triumph" Radiator, A. A. Griffing Iron Co., cast iron, 8 loops............	40.00	230	65	165	......	4.40	......	275	1.67	264	
24		Peirce "Excelsior" Cast Iron Radiator, 10 sections.........................	40.00	228	63	165	......	4.50	......	281	1.70	269	
25		"Art" Radiator, cast iron, 6 panels.......................................	18.00	228	74	154	......	4.22	......	264	1.71	270	
26		„ „ „ „ 12 „ double..	36.00	228	70	158	......	3.15	......	197	1.25	200	
27		Detroit Radiator, Exeter Machine Co., cast iron, 8 loops..................	40.00	228	73	155	......	4.09	.....	255	1.65	261	
28		Single Bar of Gold's Pin Indirect Radiator, 3″×6″×3½′..................	10.00	228	70	158	......	6.00	......	375	2.37	375	
29		Howard Oxbow Radiator, 2 loops, cast iron. Date, 1866..................	25.00	228	70	158	......	5.57	......	348	2.20	348	

In connection with the warming of dwellings, parlors, or isolated rooms, we reproduce a cut of a direct radiator, made in England, and known as a fire-place heater. This is seen to be an ordinary radiator construction, with this difference, that a fire chamber is formed inside, by omitting some of the tubes; a grate is then inserted, and a fire made in the regular way; or, what is better, a gas back-log employed, which may be lighted with the least trouble, and all annoyances from coals and ashes be avoided.

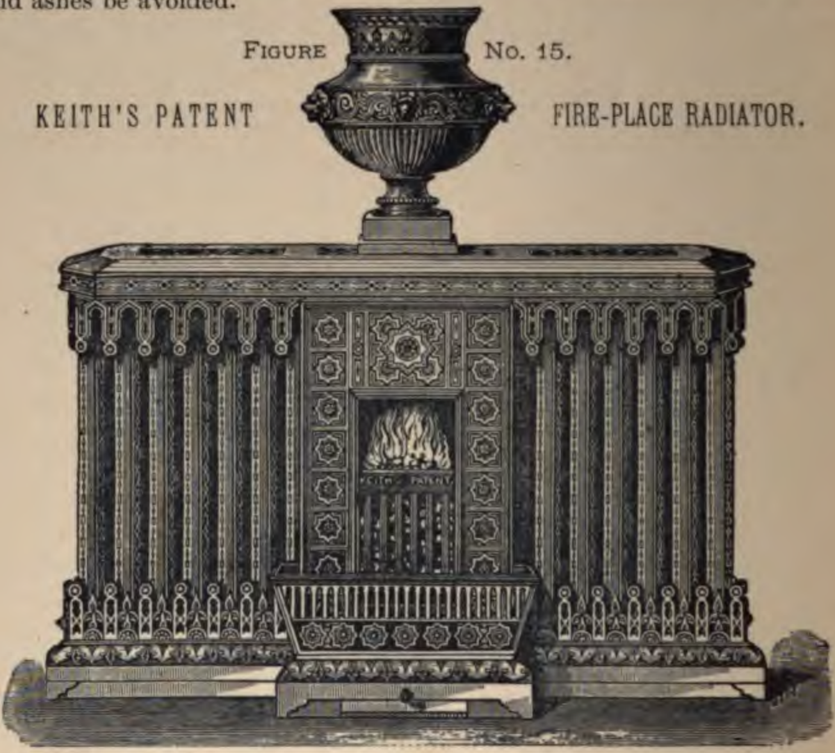


FIGURE No. 15.

KEITH'S PATENT FIRE-PLACE RADIATOR.

In this form it will be seen that the fire-place heater combines within itself a *boiler and radiator*, all other pipes and fittings being avoided. The urn on top is at the same time the expansion tank and also an air moistener, a space in the upper part being left for holding water. In summer time the urn makes a nice receptacle for ferns and flowers.

When the heater is set, arrangements may be made for the introduction under it of fresh air, so that desirable sanitary conditions are here provided for. If set in a chimney breast, provision should be made for a discharge of air from the rooms, which is made very effective by the waste heat from the fire before mentioned. Certainly for an invalid, or other person not hampered by the extra cost, here seems to be the perfection of heating and ventilating arrangements for single, and possibly double, rooms. Similar devices of this kind are made in this country.

RADIATOR EXPERIMENTS.

As the matter of radiator experiments is of much interest, and in view of our tables and the fact that somewhat conflicting results have been obtained by competent and presumably disinterested engineers, we will look somewhat into the matter; and, as Mr. Geo. Barrus gave, not only all his data, but drawings to scale, we will avail ourselves of them, in order to do him justice, while explaining wherein we differ from his final conclusions. As to the general facts there may be no question.

Plate No. 29 and table of conditions and results show that it was the intention of the engineer at least to furnish his employers and the public the facts. If there were any errors in employing so many machines to control each separate operation they were such as applied to both radiators alike.

The manufacturer or agent for radiators constructed of wrought-iron pipes claims a superiority, not only for his particular construction, but for its high efficiency, because made of wrought-iron pipe tubes; while the foundry man, producing a cast-iron radiator, insists that his material is the best.

Both parties to this quarrel, so to speak, have made or caused to be made certain experiments to prove the superiority of wrought or cast material, and their particular method of putting it into radiators.

The experiments for a cast-iron radiator were made a few years ago by the Detroit Radiator Company and a professor of a young ladies' seminary in that city, guided in his operation by the mechanical talent of the foundry where the radiators were made.

As the writer has been obliged to dissent from the conclusions reached in both cases, and also to criticise the methods employed, he deems it but fitting and due to the parties interested, and to his readers, to explain quite fully the reasons for such dissent.

In doing so it need not be inferred that he questions either the ability or the honesty of the parties experimenting. Mr. Geo. Barrus is a graduate of the Boston Institute of Technology, while the firms that employed him are beyond suspicion of collusion to draw out unreliable reports, or, as has been stated, of combining to parade such to the injury of their competitors. That the circular describing what they had done was not wise or well chosen, is only a matter of general comment, at least among engineers who have knowledge of such matters.

The Detroit Radiator Company committed a like error, when they published and distributed a circular in red and blue lines, setting forth the superior merits of their cast-iron radiator, and asserting that the Walworth wrought-iron radiator of the same si [illegible] was "*so far behind as not to be worthy of compa* [illegible]

STEAM HEATING.*

SOME INTERESTING EXPERIMENTS IN BEHALF OF THE DETROIT STEAM RADIATOR COMPANY.

In Detroit for the past ten days some experiments have been performed which are of much practical value. The Detroit Steam Radiator Company, owning a patent on a contrivance for steam heating, determined to learn the intrinsic value of their radiator by means of a correct and scientific test. For this purpose an air-tight compartment or box, five feet high, three feet wide, and five feet long, was made of wood, with a perforated board partition six inches from the bottom, and another the same distance from the top on the inside. Between the two perforated partitions was introduced an improved Detroit steam radiator. Proper steam connections were made, having steam gauges at the points of ingress and egress of steam next to the outside of the box. An opening four inches square was made at the bottom of the box, to allow a pipe connected with a blower to be attached ; an opening of the same dimensions was also made at the top, to allow the air to be blown into the bottom of the box, thence through the perforated partition below the radiator, thence from around the radiator, through the upper perforated partition into the outer air.

The company invited Benjamin F. Comfort, instructor in physics at St. Paul's Grammar School and lecturer on natural philosophy at Leggett's Ladies' Seminary, to oversee the experiment and to take observations. Charles H. Hodges, Superintendent of the company's works, in connection with Mr. Comfort, after careful observation and reasoning, found the following surprising results:—

Placing a Fahrenheit thermometer at a point where the air entered the blower, and then at the opening whence the air came out of the air-tight box putting another, the blower was started, forcing 750 cubic feet of air every minute, and the steam was let into the radiator at 5 pounds pressure. In 5 minutes after the steam had entered, an observation showed the inlet air to have been at 63° and the outlet air to be at 132°. After this observation, the steam was immediately raised to 10 pounds pressure, and in 5 minutes the temperature, as observed, was : inlet 63°, outlet 138°. After each observation, the steam was raised 5 pounds, and 5 minutes afterward the next observation was taken. Thus the 750 cubic feet of air rushing through every minute, steam being at 15 pounds, was observed to be : inlet 64°, outlet 144°; 20 pounds of steam, inlet 64°, outlet 146°; 25 pounds of steam, inlet 64°, outlet 150°; 30 pounds of steam, 64° and 155°; 40 pounds of steam, 64° and 159°; 50 pounds of steam, 64° and 164°.

This experiment occupied thirty-five minutes. It was found that for every pound increase of steam pressure, the temperature of the current of air was raised 70 per cent of 1° Fahrenheit.

The foregoing results were found to show the real, intrinsic value of the Detroit radiator. It was then thought proper to subject the radiators of other manufacturers and principles to precisely the same experiment, and thereby determine the comparative value of the Detroit. Accordingly, a Bundy radiator of the same heating surface was put in the same box at the same temperature, and under the same conditions of forced air and steam. At 5 pounds of steam in 5 minutes the inlet air was observed at 62°; outlet, 115°; steam, 10 pounds, 63° and 118°; at 15 pounds, 64° and 122°; 20 pounds, 64° and 126°; 25 pounds, 65° and 132°; 30 pounds, 65° and 134°; 40 pounds, 65° and 138°; 50 pounds, 65° and 145°.

From these figures it is seen that in raising the steam from 5 pounds to 50 pounds pressure a net gain of 27° of temperature was made, which is 60 per cent of 1° for every pound increase of steam pressure. It is also seen that the Detroit started from a higher standard of temperature, namely, 132°, and also produced 10 per cent of 1° more heat for every increase of 1-pound pressure of steam.

The results obtained from the Walworth radiator fell below those obtained for the Bundy, and therefore are not needed for comparison.

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* *Detroit Free Press*, December, 1885.

The writer noticed and reviewed the experiments in the *Buffalo Commercial* of February, 1885; and, as this is to the point in the present matter of radiator experiments, and as showing how the reverse of any other result can be honestly produced, we insert the two articles in full, as containing both the statements in the report and the author's reply.

BUFFALO, February 18, 1885.

EDITOR BUFFALO COMMERCIAL:

In a late issue of the Detroit *Free Press* of December 18 appeared an article under the head of "Steam Heating," reciting that, at the works of the Detroit Steam Radiator Company, some experiments had been performed which were of much practical value, the tests being of a "correct and scientific nature," to which end a professor of physics and natural philosophy attended to oversee the experiments and take observations. It appears that the company above mentioned, desiring to learn the "intrinsic" value of their "contrivance for steam heating" and the comparative value of other similar devices, proceeded in the following singular manner. The report states: "For this purpose an air-tight compartment or box, five feet high, three feet wide, and five feet long, was made of wood, with a perforated board partition six inches from the bottom, and another the same distance from the top on the inside. Between the two partitions was introduced a Detroit 'improved' steam radiator. Proper steam connections were made, having steam gauges at the points of ingress and egress of steam next to the outside of the box. An opening four inches square was made at the bottom of the box, to allow a pipe connection with the blower to be attached; also an opening of the same dimensions was made at the top, to allow the air blown into the bottom of the box to pass thence through the perforated partitions below the radiators, thence from around the radiator through the upper partition into the outer air."

Arranging the blower to force 750 cubic feet of air per minute, and raising the steam pressure 5 pounds at each observation, certain results of temperatures of the issuing air were noted. Condensed, the summary runs as follows: The Detroit radiators raised the current of air (750 cubic feet per minute) 78 per cent of 1° for each increase of 1 pound pressure on the gauge, from 5 to 50 pounds; that a Bundy radiator, of the same size and under the same conditions of air and steam, raised the air only 60 per cent of 1° for each pound increased of steam pressure; while the Walworth radiator fell so far behind the Bundy as not to be needed for comparison.

Apparently these "surprising results" gave satisfaction to the family group assembled to witness them; and might be entertaining reading to persons not acquainted with such goods and the methods usually employed by engineers and practical men, when testing radiators for their "intrinsic" value.

What a manufacturer or purchaser would really wish to know would be, what is the comparative value per square foot of surface of a radiator when under the same conditions of steam and air that would prevail when standing in a room designed to be warmed by it, and not what would be the results under circumstances never employed in practice.

Had the goods tested been *indirect* heaters instead of *direct* radiators, the dark cabinet and perforated partitions might not have been so far out of order, and the surprising results quite natural consequences, only lacking much other data to verify them. In either case, both radiators should have been *in the cabinet at the same time*, to ensure fairness; as one revolution of the shafting more or less would alter the speed of the fan, and thus the amount of air delivered.

Having myself made many of these tests, and owning, perhaps, the most complete list of the experiments of prominent engineers, I submit for the benefit of persons who may care to look into these interesting matters a few of the conditions necessary and generally employed in obtaining comparative data, or in learning
true value of radiators.

1st. That any data of this nature, to be valuable, should emanate from persons *thoroughly competent and entirely disinterested.*

2d. That direct radiators, to be tested and compared, shall be as nearly alike in size, height, and number of tubes wide, as the construction of each will allow.

3d. That two or more radiators, to be tested, be placed in the same room and condition as when in use, protected from all draught and influence upon each other, temperature of room say 60 to 70°, and steam pressure 5 to 10 pounds, as employed in general low-pressure heating operations.

4th. The work to be observed and reported upon is the *radiating* and *conducting* power of the machine, which is found by the cubic feet of steam condensed, and measured by the amount of water resulting, which, being credited and divided by the square foot of radiator, gives the "units of heat received from the steam and transmitted to the air and walls of the room being warmed, per square foot of surface per hour." Turning to my own experiments made under the above conditions, I find data from the radiators referred to, and one other, a cast-iron tube-radiator of late construction. * Tabled and in the order of their results, they stand as follows:—

	Sq. ft. of surface.	Unit of heat per sq. ft. per hour.	Compart., val. per sq. ft. heating surface.
Walworth	48	322	.30
Reed	37	308	.28 7-10
Bundy	60	254	.23 6-10
Detroit	40	242	.22 5-10

Steam pressure 5 pounds, temperature of steam 227°, temperature of room 70°, average of three trials three hours each.

Just here comes in a result, which manufacturers, agents, and consumers would do well to consider; namely, that however good the general plan and make of a radiator may be, if *over-measured* (*under the pressure of competition*) it will fall behind when weighed in the unerring balance of condensation per square foot of surface, exposed to the air, and, while some arrangements of tubes and construction of "bases" are more favorable to circulation than others, the shortage will generally be found in *over-estimating the actual heating surface employed.* And when the statement is thrown out, that a certain radiator is 25 per cent less in weight for a given surface than another, it is safe to presume that such surface has been extended and diluted, so to speak, to its own loss.

The pleasing theory that ribs, spurs, or rings outside the actual pipe or tube can be measured and sold as actual heating surface, disappears before the crucial test of condensation, and the "fraud" (intentional or otherwise) stands revealed.

There is, however, one notable exception to this rule, in the Gold pin *indirect* central-connection radiators. These were over-measured at first, but brought down to their actual surface of 8¾ square feet per bar. They are excelled by no device of cast-iron, or equal area of wrought-iron tubes for indirect surface.

Returning to the subject matter of the test reported, it is easy to see that the shape of the base of the radiators placed in the "dark cabinet" would have much to do in "deflecting" the forced currents of air away from the tubes; while a slight variation of speed of the fan would more than account for the not large difference of temperatures of the discharged air; and still the results have no practical bearing on either radiator!

Having no interest in either of the radiators, and not having conversed with any of the parties referred to, I have simply reviewed the conditions and submitted my result, with the sole desire to see fair play, and justice done to both manufacturers and consumers.

Respectfully yours,
JOHN H. MILLS.

Buffalo, February, 1885.

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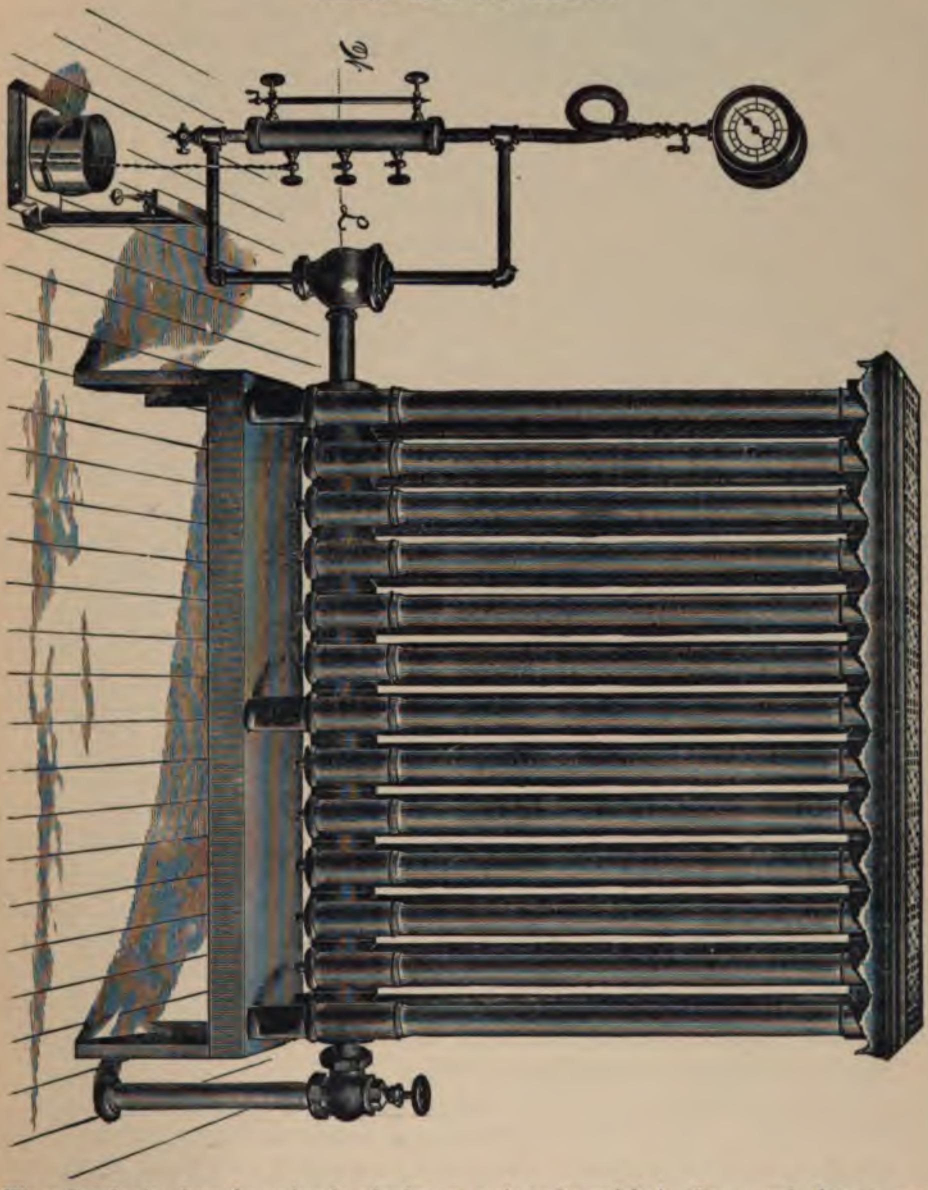
* The Bundy and Detroit radiator patterns have since been slightly changed.

PLATE NO. 28.

Mills Apparatus for testing Radiators and Heating Surface, consisting of a single fitting carrying Glass and Steam Gauge and Try Cocks.



Water Overflowing from the syphon into bucket on scale to be weighed. One pound of water condensed at 180° = 1,000 heat units. Or ounces of water per square foot of surface per hour x 62½ equals Heat Units Recovered.

See experimental results, Tables Nos. 10 and 11.

Plate No. 29 shows all the arrangements and conditions which were present at the time and place Mr. Barrus made his test referred to, except the two enlarged sections of the radiator, A and B. These were added to the drawing for the better understanding of the smaller plan, and as being desirable, in order to show the different construction of the base of each radiator; but for the large amount of air thus admitted through the base of the Bundy the work accomplished would have been still less. Altogether, this is an interesting study in the value and effect of radiant heat as applied to direct radiator construction.

In the first place, while each radiator was substantially of the same rated square feet of surface, they were in no other respects alike.

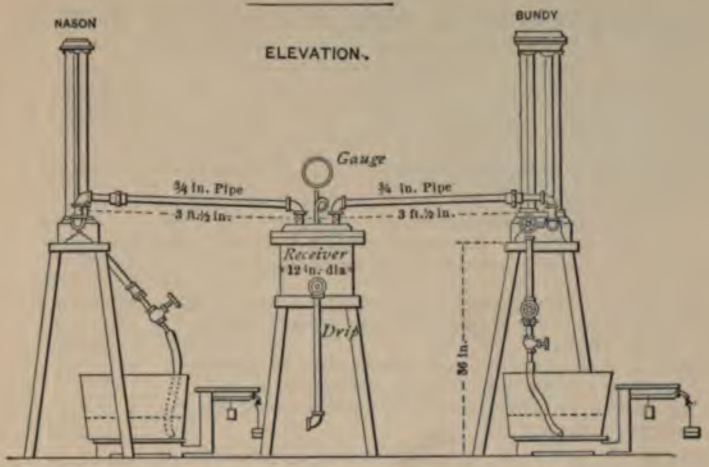
The Nason radiator, as seen by the sketch, was 50 inches long and 6 wide, while the Bundy was but 28 inches long by 10 inches wide (omitting the fractions). Thus the exposures of the two surfaces to the surrender of radiant heat were the *reverse* of each other; and, as the part that radiant heat plays, compared to that of conduction, is (table No. 9) nearly the same for *free* surface, the proportion of heat surrendered in the same time by the *unlike* surfaces and exposures would be very different.

Again, the effect of one radiating surface upon the other would not be the same; the Bundy radiator would affect the Nason radiator less than the Nason would affect the Bundy. That is, in the position shown, the Bundy took the larger effect of *radiant heat* in front from the Nason, and it also was in a reflex heat from the wall behind, thrown from the two radiators. True, in some of the experiments the positions of the radiators were reversed without apparently changing the results, as we could hardly expect it would, seeing the great *differences of form and surface exposure*.

Passing to the effect of "bunching" one radiator and drawing the other out, it should be seen that, to have made a fair comparison, the Nason radiator should have been 4 x 12 instead of 2 x 24; in that size it would have been *similar in surface exposure*, and doubtless in effect, as the ratio of effect is 10 *per cent less for each additional row of tubes.* Had the Bundy radiator been sixteen pipes in a single row, the exposure would still not have been equal, but the results would have been very different. Of course, if neither radiator was made, or could be had, except in those disproportionate groupings, there might be some reason for the unequal surfaces and conditions adopted.

So far as testing radiators together is concerned, there seems no necessity or reason except economy of time; as radiators so placed are sure to affect each other, unless a non-conducting apron or screen is placed between. Neither is it vital that radiators should be tested at the same gauge pressure or air temperature, when all experiments are, or should be, reduced to *standard conditions.*

PLATE NO. 29.



Experiments made by Geo. H. Barrus, M. E. 1886.
Reviewed by J. J. Hogan in "Metal Worker" Jan. 14, 1888.

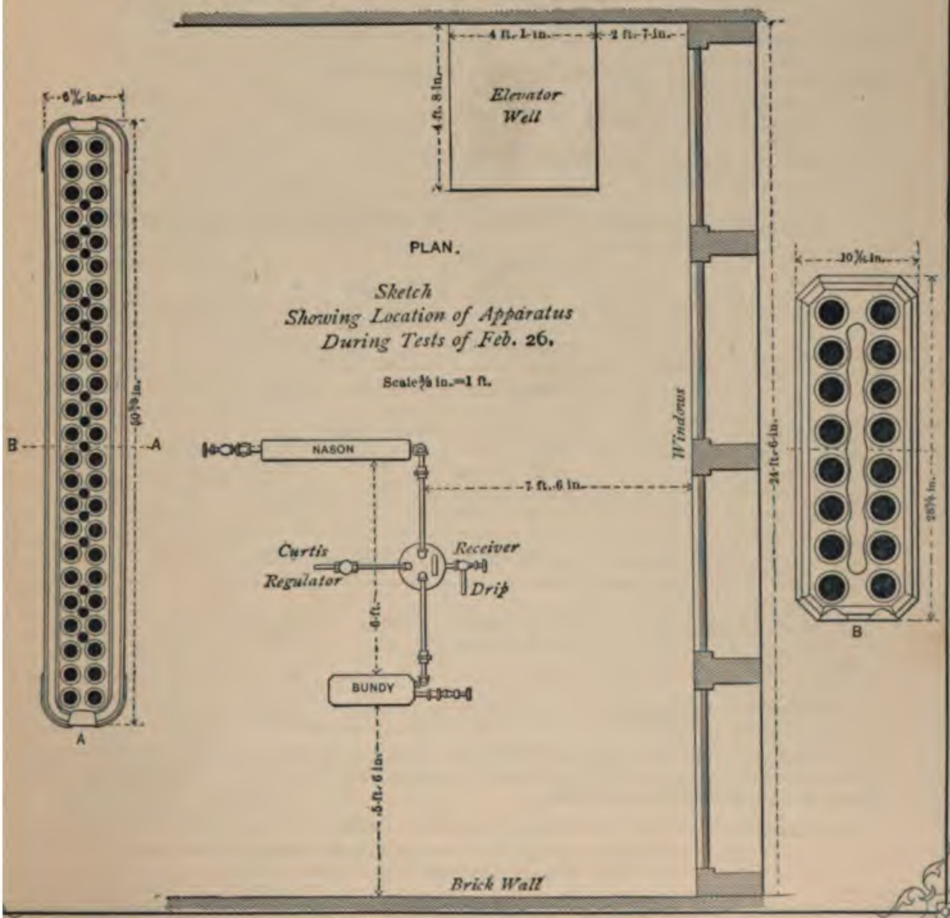


TABLE No. 10½.

FULL SUMMARY OF DATA AND RESULTS OF TESTS.

Nason and Bundy Radiator, Feb. 26, 1886.*

	NAME OF RADIATOR,	NASON.	BUNDY.
	Commercial Rating of Surface . . square feet	48.	48.
	Actual area of Radiating Surface . . square feet	47.58	43.30
1	Duration of tests . . . . hours	8.	8.
2	Total weight of steam condensed . . . . lbs.	138.56	106.24
3	Average weight of steam condensed per hour . lbs.	17.32	13.28
4	Weight of steam condensed per hour, per square foot of *actual surface* . . . . lbs.	0.364	0.307
5	Total number of units of heat given off per hour B.T.U.	16,542.3	12,683.7
6	Units of heat given off per hour, per square foot of actual surface . . . . B.T.U.	347.6	293.2
7	Units of heat given off per square foot of actual surface per hour per degree difference of temperature between steam in radiator and the surrounding air . . . . . . B.T.U.	2.04	1.72
8	Average pressure in receiver (above atmosphere) corrected for error of gauge . lbs. per sq. inch	8.57	
9	Average height of barometer . . . . . inch	29.65	
10	Temperature of steam corresponding to pressure in receiver . . . . deg.	235.7	
11	*Assumed temperature of condensed water* . . . deg.	229.6	
12	Total heat above zero of steam having the pressure in the receiver . . . . . . B.T.U.	1,185.8	
13	Average temperature of air 5 feet 6 inches from Nason Radiator . . . . deg.	64.37	
14	Average temperature of air midway between radiators . . . . deg.	66.63	
15	Average temperature of air 5 feet 6 inches from Bundy Radiator . . . . deg.	64.07	

RECAPITULATION OF HOURLY QUANTITIES AND AVERAGES.

Conditions.	Date.	Number of Test.	Weight of steam condensed in 1 hour.		Gauge pressure (not corrected).	TEMPERATURES.		
			Nason.	Bundy.		5½ feet from Nason.	Midway between Radiators.	5½ feet from Bundy.
			lbs.	lbs.	lbs. per sq. in. above atm.	Deg. F.	Deg. F.	Deg. F.
Radiators in position shown in Sketch No. 1 (covers on).	Feb. 26	1	17.	13.1	8.3	66.3	69.2	67.7
	“	2	16.88	12.91	8.2	66.6	70.1	68.7
	“	3	16.94	12.84	8.3	67.1	70.9	69.5
	“	4	16.38	12.53	8.3	67.7	71.5	69.5
	Averages.		16.80	12.84	8.27	66.92	70.42	68.85
Radiators in position shown in Sketch No. 1 (covers removed).	Feb. 26	5	17.38	12.97	8.2	68.1	71.	69.9
		6	16.88	12.59	8.1	67.9	71.8	69.7
	Averages.		17.13	12.78	8.15	68.0	71.4	69.8

It appears from these figures that the Nason radiator gave out 30.4 per cent more heat in the gross than the Bundy radiator, and 18.6 per cent more heat per unit of actual radiating surface.

GEO. H. BARRUS.

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* Published by the Nason Radiator Co., No. 71 Beekman street, New York. Reviewed by Hogan in *Metal Worker*, Jan. 14, 1888.

Referring to the condition and results of the foregoing experiments, we note the following differences between the final results and experiments made by other parties on the same surface: —

The generally higher duty credited to the wrought-iron surfaces of 347 units becomes, when reduced to the temperatures 228° and 70°, (*standard condition of steam and air*) 321 *units*.

The 293.2 units credited to the Bundy, reduced to *standard conditions*, become 271 units. The writer's tests of the same radiator and conditions give 298, while a test made at the works gave 314 units, or an average for the two tests of 306, or 6 units higher than the two wrought radiators above referred to, and these tests were made up from the commercial rating of both radiators. If, now, the Bundy is really over-measured, as shown in the foregoing data, its actual surfaces, foot for foot, must be nearly equal to either of the wrought-iron radiators tested with it, provided that it is tested alone and with no detracting influences and conditions as to size and exposure.

The experiments of the writer with the Walworth and Nason 2 x 24 pipe radiator give an average of 300, or 21 units per foot less than Mr. Barrus obtained. (Standard condition as above explained.)

As concluding our remarks on the comparative value of the two materials, cast or wrought iron, as heating and radiating surfaces, we may glance at the same table, No. 11, and note at the heading each side of the "description of radiators" that 10 wrought-iron radiators from the experiments gave 307 units of heat, and that 10 cast-iron radiators gave 310, or less than 1 per cent difference.

At the bottom of the same table, under the heading "horizontal pipes," we may note that 1-inch, 2-inch, and 3-inch pipe are compared. The calculated work that should be done (as in table No. 9) and that found by the experiments substantially agree, and prove the correctness of both the table and diagram. The average of all radiators (lower right-hand column, table No. 11) is seen to be 312 units, and the average of the horizontal pipe is 370 units.

We here note the value of heating surface, obtained as a mean of the experiments of J. J. Nason, with *plain cast-iron* and *extended surfaces* =314 units. While Mr. Nason found for 1-inch wrought-iron pipe (single line) 447 units, he obtained for his vertical radiator, 1 x 24 (single tubes), 357 units, and for a radiator, 2 x 24, 48 feet, 2 rows wide, 267 units. Thus we see what relation the *material*, and what the *position* and *construction* have to do in determining duty and value of either wrought iron pipe or cast metal when brought close together for *direct radiators*.

EXPLANATION OF TABLE NO. 11.

In order to compare radiators fairly, they are arranged in the following table, No. 11, according to their *size* and *condition*, the first being an average of 13 feet, for which we find a value per square foot of radiator of 350 units.

The next group of 23 foot radiators gives us 342 units, the next of 30 feet 312, while double this size gives us but 277, as against the first group of 350, or a difference of 21 per cent less duty for the large radiators over that of the smaller.

Besides many minor facts, tables Nos. 10, 11, and 12 will be found to embody most of the conditions of experiments and researches into the value of materials of radiators, also of pipe for heating surfaces.

The whole is by different engineers from 1862 to 1888.

It should be clearly understood that in all cases except the wrought and cast iron pipes the square feet of surface set in column A is that given by the manufacturers and placed upon their price-lists, and further known as the *commercial rating*.

Thus, when a radiator is over-marked, it operates to give it a low duty per square foot; since, in testing, the total work is divided by the supposed or rated feet of surface. Thus, if a radiator is credited with forty-eight square feet, and has only forty-two or forty-three actual, its rating will be lower than if its work were divided by its actual surfaces.

That there are many radiators on the market that do not contain within from 15 to 25 per cent of the square feet of surface for which they are sold, is doubtless true; also, that if, even by great stretch of ingenuity and the tape line, something near the number of square inches is figured out, the real value of the final combination of any form of tubes (with bases and without) is far from what is represented and perhaps honestly believed by the manufacturers and their agents.

The companion diagram, No. 18, is for cast-iron surface, two of the best radiators and forms of pipes being compared. As it is intended in no way to raise or depress one firm's goods over those of another, personal mention of manufacturers is omitted except in the tables, where it is necessary to distinguish construction and other conditions.

It may also be briefly explained here that the factor of work accomplished by the radiator is taken at 1000 heat units per pound of water condensed and cooled from the temperature of the steam to 180° Fahr., and principally consists of the latent heat of the steam, with this difference, that a separate calculation is not made each time, or for each slight difference of steam pressure. ***As the same data and factor of value are taken for all the experiments, there can be nothing unfair or partial to any radiator or to any person interested, the final results being reduced to the same standard of conditions; viz., steam at* 5 *lbs.* = 228°, *air,* 70°.**

Experiments with Direct Radiators, selected from the Reports of different Engineers. Arranged in the Order of the Size or Surface tested, the Final Work or Duty being reduced to Uniform Conditions of Steam and Air. (Col. J.)

TABLE NO. 11.

No	DESCRIPTION OF RADIATORS, AND DATES OF EXPERIMENTS.		Square Feet of Surface, as rated.	Gauge Pressure.	TEMPERATURES.			Ounces of Water Condensed per Foot per Hour.	UNITS OF HEAT.			
					Steam.	Inside Air.	Difference of Temp., Air and Steam = C − D.		Of Evaporation per Lb. Water Condensed.	Per Foot per Hour = F × G ÷ 16.	Per Degree Diff. Steam and Air = H ÷ E.	Uniform Steam 5 lbs. Air 70° = I × (228 − 70).
			A	B	C	D	E	F	G	H	I	J
1	J. Nason, 1862,	M.&T. C. I. Radiator, curved rib,	14	1	215	70	145	4.30	963	260	1.80	285
2	J. H. Mills, 1879,	Old Washboard, 16 years old,	15	5	228	75	153	6.13	954	366	2.26	378
3		New " from same pattern,	15	5	228	75	153	5.80	954	346	2.26	357
4		Reed C. I. vert. tube, open base,	12	5	228	73	155	5.00	954	300	1.94	307
5		Mills C. I. hor'l 1 bar, 14 in. high,	8	5	228	70	158	6.22	954	370	2.34	370
6		" " plain surf. 2 bar, 34 in.	16	5	228	70	158	5.33	954	318	2.01	317
			Average 10 Square Feet, . . .									**336**
7	J. H. Mills, 1879,	Mills C. I. horizontal 3 bar, 34 in.,	24	5	228	76	152	5.03	954	300	2.00	316
8		Walworth W. I. vert. tube, solid b.,	24	5	228	73	152	4.82	954	287	1.89	299
9		Nason W. I. vertical tube, 1 x 20,	20	5	228	77	151	5.87	954	350	2.32	367
10		Walworth W. I. vert. tube, 1 x 20,	20	5	228	77	151	5.87	954	350	2.32	367
11	J. J. Nason, 1862,	Nason W. I. Radiator, 1 x 24,	24	1	215	70	145	5.70	963	345	2.38	376
12		Clogston C. I. vert'l, ribbed pipe.	21	1	215	70	145	3.80	963	230	1.59	252
			Average 20 Square Feet, . . .									**329**
13	A. A. Griffing Iron Co. 1886	Gold's Compound Coil, 2 x 8,	32	2	219	69	150	3.78	960	227	1.51	239
14		Bundy C. I. ver. tube, op. b., 1 x 11,	33	2	219	69	150	5.20	960	312	2.08	329
15	J. R. Reed,	Shawmut C. I. hor. bar, no b. 3 br.	30	3	222	49	173	5.79	958	347	2.01	318
16	J. H. Mills, 1884,	Mills C. I. horizontal 3 bar, No. 9,	27	5	228	70	158	5.39	954	321	2.03	321
17		Reed C. I. vert'l tube, open base,	27	5	228	70	158	5.26	954	314	2.00	316
18		Bundy C. I. Water Radiator,	32	3	222	65	157	4.36	958	261	1.66	262
19		Walworth W. I. 2 rows, 16 pipes,	32	5	228	60	168	5.49	954	327	1.95	308
			Average 30 Square Feet, . . .									**305**
20	J. J. Nason, 1862,	Box Radiator, C. I., vertical rib,	44½	1	215	70	145	3.63	963	219	1.51	239
21	J. H. Mills, 1884,	Whittier C. I. hor. bar, ext. flat pin,	37½	9	237	70	167	3.52	947	208	1.25	198
22		Detroit C. I. ver. tube, 1st pattern,	40	9	237	70	167	4.46	947	264	1.58	250
23		Mills C. I. horizon'l 3 bar, No. 12,	36	5	228	54	174	6.22	954	371	2.13	337
24	G. H. Barrus, 1886,	Walworth W. I., 2 rows, 24 pipes,	48	9	235	51	184	6.51	949	386	2.10	332
25		Bundy C. I. vertical tube,	48	9	235	51	184	4.78	949	284	1.54	243
26		Nason W. I., 2 rows, 24 pipes,	48	9	236	64	172	5.78	949	348	2.02	319
27	A. A. Griffing Iron Co. 1886,	Bundy C. I. vertical tube, 2 x 8,	48	2	219	79	140	4.45	960	267	1.91	302
			Average 40 Square Feet, . . .									**282**
28	J. Nason, 1862,	Nason W. I., 2 rows, 24 pipes,	48	1	215	40	145	3.93	963	238	1.84	259
29	J. H. Mills, 1879,	Mills C. I. 2, 3 bars, coupled,	48	5	228	72	156	4.84	954	289	1.85	292
30		Walworth W. I., 3 rows, 16 pipes,	48	5	228	72	156	4.50	954	269	1.72	273
31	J. R. Reed,	Whittier, 4 x 3,	50	3	222	49	173	4.35	958	260	1.50	237
			Average 50 Square Feet, . . .									**265**
32	A. A. Griffing, 1886,	Eureka C. I., ring pipe,	80	2	219	79	140	3.26	960	196	1.40	221
33	J. H. Mills, 1886,	Peirce C. I., vertical flat tubes,	68	5	228	62	166	3.83	954	227	1.35	216
34		Bundy C. I., vertical tubes,	60	9	237	74	163	4.82	947	285	1.75	277
35		Walworth W. I., vertical tubes,	48	5	228	72	156	4.50	954	268	1.72	268
36		Mills C. I., 6 bars, coupled, No. 9,	54	5	228	56	172	5.24	954	312	1.81	286
37		The "Union" Rad., 1886, C. I.,	58	2	218	68	150	4.50	960	300	2.00	316
	HORIZONTAL PIPES.		**Average 60 Square Feet, . . .**									**264**
38	1 inch Pipe,	By Theory of Cond. & Rad. Heat,			210	60	150			399	2.66	Miscellaneous.
		" Experiment, J. Nason, 1862,	33⅓	1	215	70	145	6.56	963	396	2.73	
39	2 " "	" Theory,			220	60	160			356	2.23	
		" Experiment, J. H. Mills, 1886,	10	2	220	61	159	6.12	960	367	2.30	
40	3 " "	" Theory,			210	60	150			303	2.02	
		" Experiment, J. Nason, 1871,	4	1	215	70	145	5.50	963	333	2.33	
41	12 " "	" Theory,			286	70	216			608	2.76	
		" Experiment, C. B. Richards,		40	286	70	216		912	690	3.20	

DIAGRAMS SHOWING RADIANT HEAT. No. 17.

Free Rays

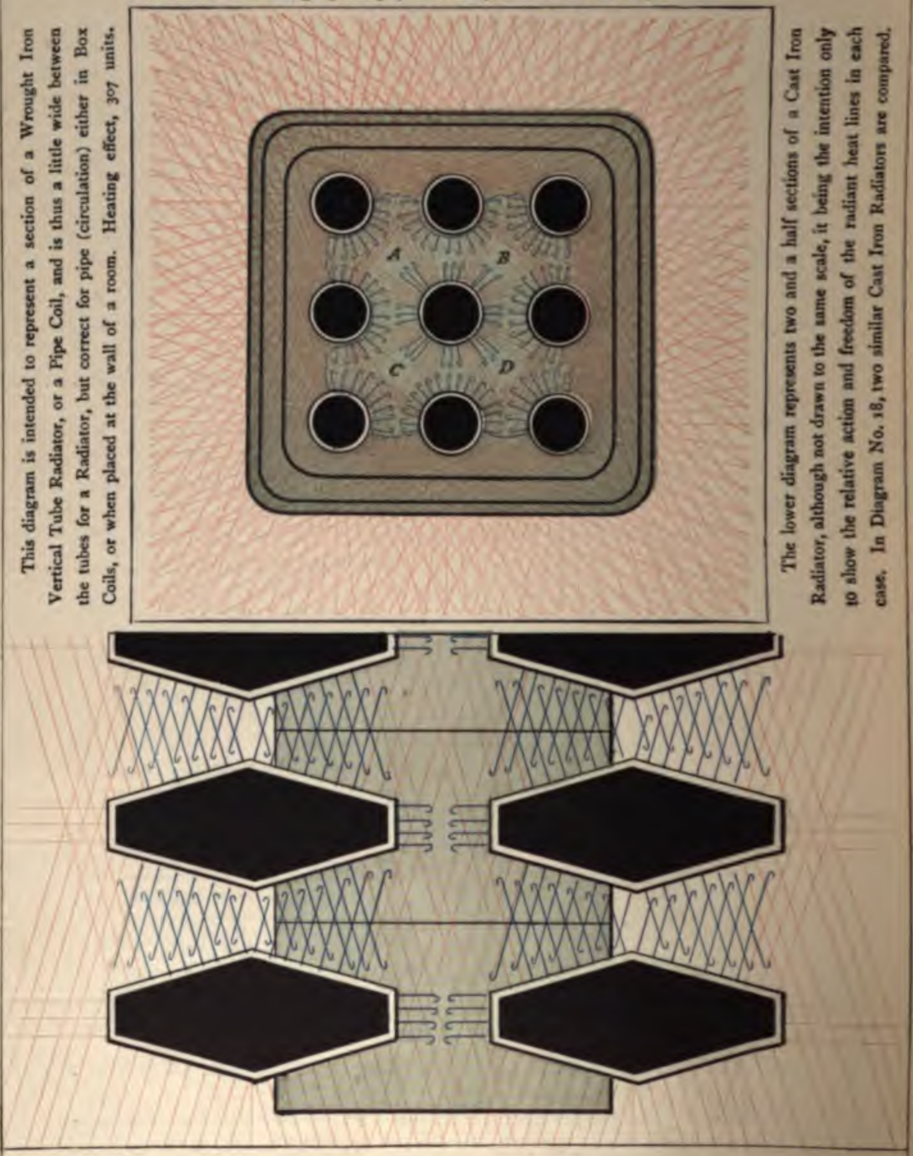
Suppressed Rays

Scale: ¼ inch = 1 inch.

Heating effect, 307 units. (See Table No. 11.)

This diagram is intended to represent a section of a Wrought Iron Vertical Tube Radiator, or a Pipe Coil, and is thus a little wide between the tubes for a Radiator, but correct for pipe (circulation) either in Box Coils, or when placed at the wall of a room. Heating effect, 307 units.

The lower diagram represents two and a half sections of a Cast Iron Radiator, although not drawn to the same scale, it being the intention only to show the relative action and freedom of the radiant heat lines in each case. In Diagram No. 18, two similar Cast Iron Radiators are compared.



EXCELSIOR RADIATOR.

Heating effect, 246 units. (See Tables Nos. 10 and 11.)

CHAPTER XIX.

CAST-IRON RADIATOR CONSTRUCTION.

FOLLOWING the scientific part of our subject, we may now proceed to another and important element affecting the work of radiating and other heating surfaces; viz., their mechanical construction and surface exposure.

On this subject we shall not be able to cite many authorities, as apparently but few writers have considered the important relation of *form* and *position* in the efficiency of heating surfaces; while but few have written, less have worked, with this end in view, and the great majority of radiators have been constructed with little regard to the real problems involved, excepting the natural and easy one — that of immediate profit to the foundry and machine shop.

In order to intelligently understand this chapter on construction and arrangement of heating surfaces, the two preceding chapters should be well considered, including the two diagrams Nos. 17 and 18.

In all cast-metal construction, the leading idea seems to have been the greatest amount of surface in the least space, with the least weight of iron. Whether this was the best combination to transfer the heat was not made the vital question, or whether such a combination was the best to give the purchaser the real value of his money.

With the advent of low-pressure steam heating, and later the application of water as a heating medium, especially in house warming, came a corresponding demand for different radiators and more ornamental surfaces than seemed possible with wrought-iron pipes and solid bases.

Besides the objections to the old style of solid bases, there existed the desire to reach the sectional construction, and also to escape the corresponding clumsy feature of the screen cap or covering of all the wrought vertical tube and horizontal pipe radiators.

For a water circulation a top cross [illegible] joining the upper ends of all vertical tube radiators is a [illegible] easily obtainable in common wrought-tube constru[illegible] etal section any desired water and steam pass[illegible]

For a wrought-iron water t[illegible]

That the early cast-metal direct and indirect radiators, although of somewhat homely design and even rural name (the Ox-bow and the Wash-board), gave such high results in heating power, was perhaps the spur and inspiration to all that we now have. That no later radiator has rivaled these first, is food for thought.

The writer early recognized the power of simple or uncombined heating surfaces and open construction for *direct* radiators; also, that the reverse of this arrangement must prevail where the heating surfaces were not in the rooms to be warmed.

The key to the high duty of the two radiators referred to may be clearly traced to their simpler form, being generally in single castings, and thus each square foot does its full duty in *radiation and conduction.*

Among other ideas that have prevailed at different times among the advocates of wrought material, was the somewhat singular one that cast iron, after some years of use as a radiator, underwent a change of its surfaces, or, rather, a change of its molecular particles; and thus it deteriorated, and did not give off as much heat as formerly or when new.

That this idea should obtain, is, as I remarked, singular, seeing that, as regards corrosion or rusting due to the presence of steam or the water of condensation, cast iron is less affected than wrought. This has always been noticed in wrought-iron furnaces or pipes in basements, also the superior value of all cast-iron pipes and fittings laid in the ground for carrying gas or water.

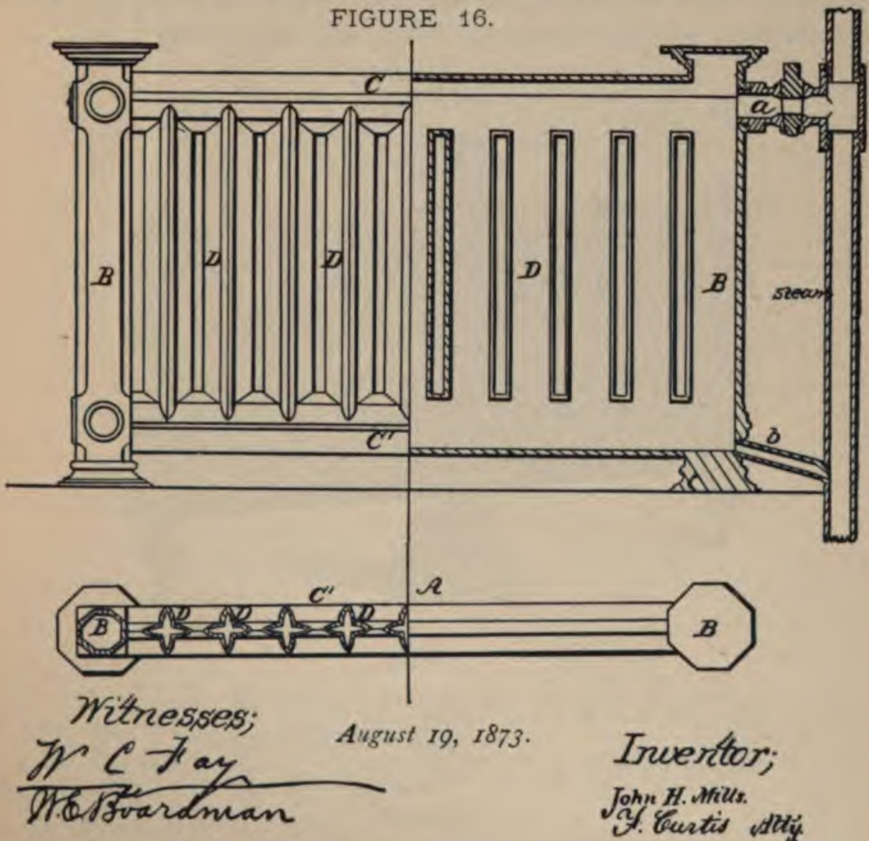
To settle the question concerning the deterioration of cast-metal, the writer in 1879 sought out a cast-iron radiator that had been in continuous use *sixteen years.* It was one of the early patterns known then, as now, as the Wash-board, which, being made in two halves and bolted together, permitted separation and rejoining in its original position. These two halves were cleaned, put into the sand, and reproduced, so that a new radiator and the old one could be tested for their intrinsic value.

The report and conditions of the experiment are seen in table No. 11, Nos. 2 and 3, *where the difference was* 1½ *per cent in favor of the old radiator, both giving a high rate of duty* (*nearly* 400 *units*).

The early heaters before referred to were not, however, calculated to stand much pressure; the joints, being numerous, made with rubber packing, gave much trouble by leaking; they were at the same time expensive to construct. It was to avoid both of the above difficulties that the radiator shown in the following drawings was designed and sent to the patent office in 1873. A claim was also made for the *form* of the tube.

In this construction it was sought to avoid joints altogether, by making a complete radiator at a single casting, and by giving the tubes a peculiar form, to secure strength, lightness, and grace; lastly, to reduce the cost of manufacture. While at first it seemed easy to accomplish these desirable results, all of them were not found compatible in the same radiator, and this pattern did not go beyond the experimental stage. The compound Gothic tube, however, survived, and may be seen with a slight modification in the Reed radiator of to-day.

FIGURE 16.



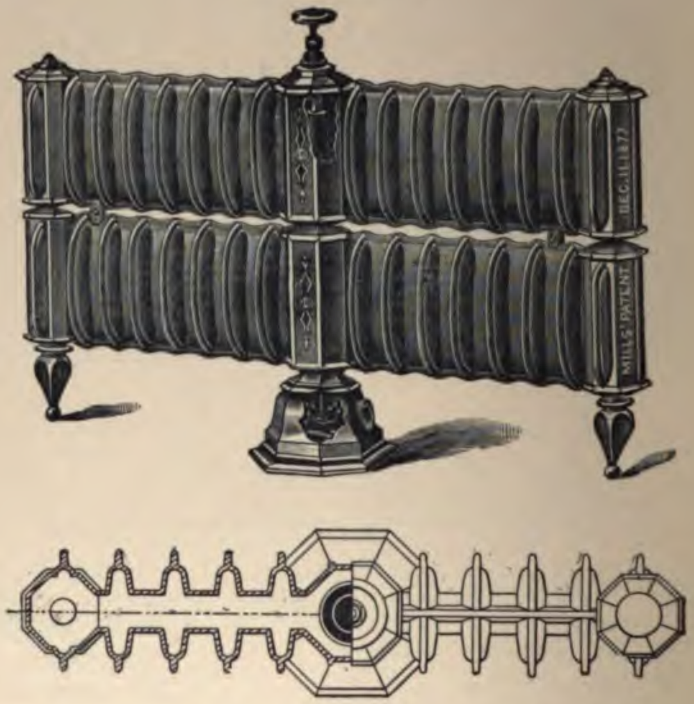
While only one feature of this early effort to secure a water and steam radiator survived, the matter was taken up again in 1877, and resulted in a form that had some decided advantages. See following page. Here the main idea was that of securing a direct sectional radiator, without a base and screen covering, and with a valve for controlling the heat as a part of the const tion

While it was seen that some j sections of a cast-metal radiator were unavoidabl e them to the minimum; or, as seen, to o rface.

The joints were, as stated, at the centre, a regular screw-threaded nipple being inserted, and the bars or sections turned together, the same as any "fitting," the ends being afterwards fastened to keep them in line; thus, all expansion was avoided, while it was easy to repair or remove a section should one get broken by frost or handling.

It was not at first supposed that a satisfactory water circulation could be secured through a continuous central passage, but the first experiments set all these fears at rest. They really did more, and proved that at that time very little was known about the phenomena of a heated water circulation in pipes and radiators, if, indeed, there is to-day

FIGURE 17.



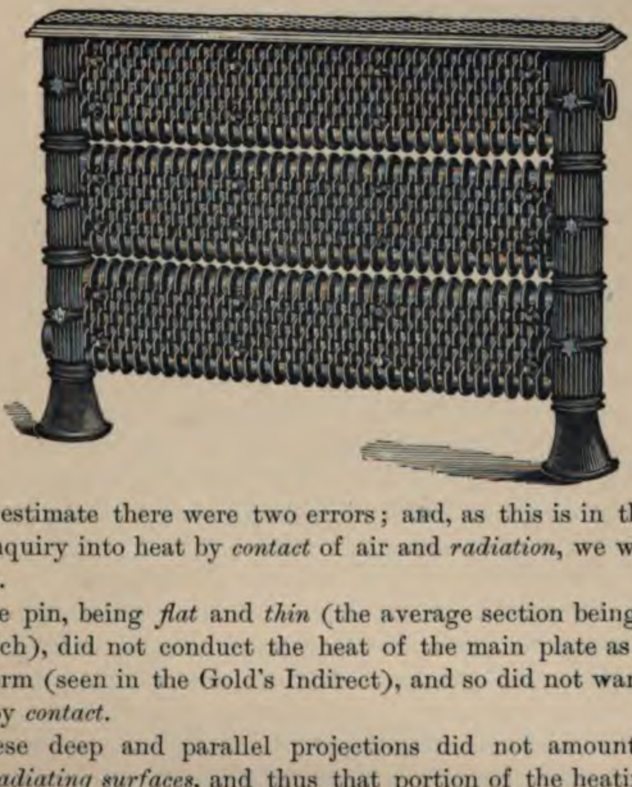
Another feature of this horizontal bar construction was the practicability of making direct radiators of any height at the same proportional cost, since the pedestal foot on which the radiators rested, and into which the connection was made, had small cost relative to the common base; thus, a single foot and one bar comprised a complete radiator ready for use and for a steam or water circulation.

Finally, that in this simple construction the highest heating duty was reached (389 units), equal to one-inch horizontal wrought tubes. See table No. 11, experiments Nos. 5, 10, and 11.

In this plate is shown the "Whittier" direct radiator, the patterns for which were made by the writer for G. W. Walker & Co. a little prior to the date 1873. While this radiator was composed similarly of horizontal bars, the circulation was also horizontal, passing continuously from one bar to the other through openings in alternate ends of each section, the same as a return bend wrought coil.

The main heating surface was, as seen, the flat pins or teeth, projecting from the faces of each bar; this surface being measured up in full, and counted as actual or plate surface.

FIGURE 18.



In this estimate there were two errors; and, as this is in the line of our late inquiry into heat by *contact* of air and *radiation*, we will briefly note them.

1st. The pin, being *flat* and *thin* (the average section being but one quarter inch), did not conduct the heat of the main plate as freely as another form (seen in the Gold's Indirect), and so did not warm the air as much by *contact*.

2d. These deep and parallel projections did not amount to anything as *radiating surfaces*, and thus that portion of the heating power of a plain plate was practically lost; at the same time, the base of the teeth covered up the best surfaces of the bar from which it projected.*

As, however, there were still good points, the manufacturers, being honest and intelligent, reduced the schedule and prices to correspond to *actual efficiency*, so that this early radiat[illegible] ired," but has been sold every year, and is still manufa[illegible] It is often used for a water circulation. See [illegible] No. 21, where the efficiency is shown to be [illegible]

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*Diagram No. 17 is also the key to [illegible]

We have seen in the preceding chapter that the massing of wrought-iron tubes in any way results in a steady and regular decrease in their possible efficiency in single lines; or, in other words, that there is a limit to the massing and drawing together of pipes and tubes intended for direct radiators.

That this difficulty is encountered when we leave the wrought tubes for the cast, is now clearly seen, and that there is even greater difficulty as we depart from the circular form to those of different angles. This is shown by the preceding diagram, No. 17, where the heating effect is seen to be 246 units per foot to 307, *or a loss of over 20 per cent.* It is proper to state that these results are obtained by experiment, the conditions of which are fully stated in table No. 11.

That the regularly *decreasing* duty of the several wrought radiators, with the numbers of pipes brought near together, is due to the suppression of radiant heat rays and also to the loss of air contact, may now be clearly seen; also that size and condition largely influence the value of the radiating surfaces.

For other sizes of pipe than 2-inch, the relative amount of heat radiated, as compared with the heat transmitted to the air by contact, becomes greater for the larger sizes and less for the smaller; thus, 1-inch pipe, under similar conditions as above for 2-inch, radiates 188 units, and conducts to the air 288, or nearly one third more.

The best result in the line of *modern* constructions for *steam* circulation appears to have been reached in the Reed radiator.

Here the form of the tubes, while not circular, embodied lines that were equally good; as, while the general outline of a section was elliptic, the form was *convex*, so that each surface *retired from* the other, instead of approaching it, as in some other constructions.

In addition to the form of these tubes, their setting in a *divided or open base* secured a larger circulation and better application of the air to *space between the tubes*, thus in a great measure making up for the loss of radiation suffered by all heating pipes standing near together; added to this there was a common-sense measurement of the tube surfaces, the whole result being the most efficient and generally satisfactory cast-metal steam radiator yet introduced.

Plate No. 30 shows both the front and end views. For other and important results of experiment and comparison, see following table of experiments, No. 11.

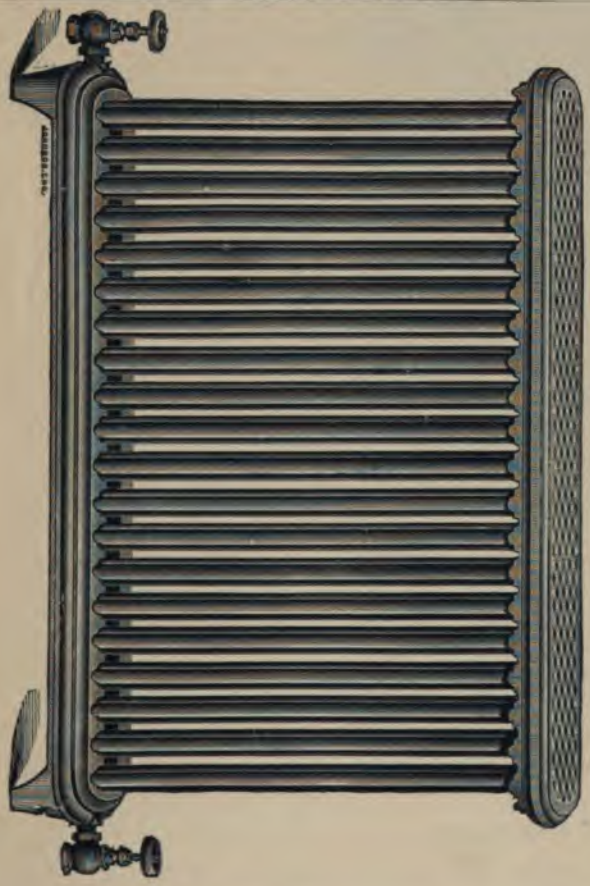
It is customary to term all appliances placed in rooms as heaters by means of steam or water, *radiators*, but the name is calculated to mislead. Indirect radiators, so-called, do not practically transmit any of their heat by radiation, except a small fraction, their efficiency depending on their *conduction by contact of the air as it passes between and over their heated surfaces.*

PLATE NO. 30.

*THE REED STEAM RADIATOR, OPEN BASE.

For tests of efficiency, see Table No. 11.

The high efficiency of this Radiator is due to the form of the pi



OVER 100,000 RADIATORS SOLD.

And to the opening through the base admitting air between the tubes.

*Manufactured by the H. B. Smith Co., Westfie

Seeing that the circular form is the best for radiating heat, and that an open construction favors both radiation and contact of the air, it is a little singular that in all the many inventions that have led up to our present position in the line of radiators, but two may be said to cover both the theoretical and practical requirements of adjacent heating surfaces without a corresponding loss of effect.

In passing on to the next favorable—we might say "phenomenal"—construction, it may be noted that the successive cast-metal radiators have progressed in the same order as the wrought, as we have the one tube in the Bundy and the Reed, the two-row section in the Bundy and others, the three-row section in the Triumph, Elite, and in the Union, while the last production, the Gurney, essays a quadruple arrangement.

The main object in increasing the rows or tubes in a base or in a single casting to be again united to form radiators is the one before stated. That there is a limit to this doubling and tripling and quadrupling of pipes and tubes, is clear, and that its general effect is to reduce the total and combined value of the surface.

The ratio of decrease in value is seen in all experiments to be over 10 per cent for each additional row of tubes added; that is, when all the tubes are the same size relatively one to another. If, as in some cases, the outer row of tubes is larger than the inner row, the loss will be more and be further increased if the outer row is drawn close together. A careful study of diagrams Nos. 17 and 18 will best show this effect, and that this may be carried far enough in a four-pipe construction to entirely suppress the radiant heat from the inside rows.

The Union triple-pipe section seems to be an exception to the general rule, in that, while increasing the number of the tubes in cross section, no decrease of efficiency follows.

The reason is seen to be the placing of one large elliptic tube in the centre, *the outer tubes being much smaller, of circular form, and at considerable distances apart, thus enabling the heat rays of the inside tubes to escape;* while the outer tubes, being, as it were, projected outwards, away from the main body tube, their heat rays are unimpeded and without adverse effect on each other or the parent tube from which they spring.

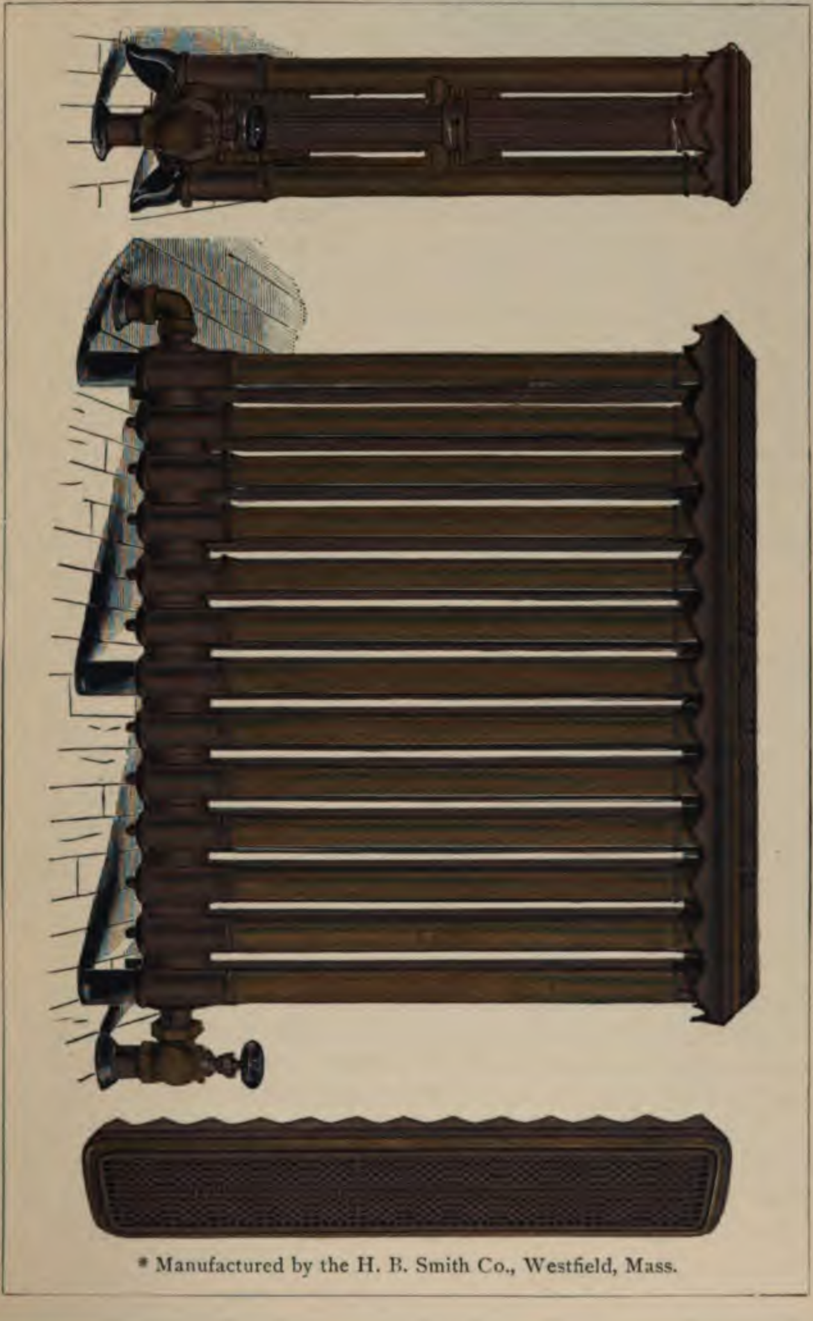
That two triple-tube constructions of similar width and height and nearly equal weight could produce so different results as 18 to 20 per cent of actual duty, is something phenomenal in radiator construction. A part of this increased work is perhaps due to a more liberal, or, rather, to a more "contracted" estimate of the actual surfaces presented, as the writer found the surfaces of the Union radiator to overrun — a fault that cannot be laid to the door of any other cast or wrought metallic construction.

PLATE NO. 31.

*THE UNION TRIPLE-PIPE DIRECT RADIATOR.

FOR WATER OR STEAM CIRCULATION.

For tests of efficiency, see Tables Nos. 10 and 11. Also, Diagram of Radiant Heat, No. 18.



* Manufactured by the H. B. Smith Co., Westfield, Mass.

If we consider direct radiators as exposing two thirds of their surface to the walls of the room (the other third radiating to itself, and so being lost for useful effect), one hundred and thirty units per square foot, or about 36 per cent of the total heat, under average temperatures, will be a rough average approximation to the amount of heat given out by radiation alone with low-pressure steam or hot-water circulation.

Since the proportions of heat, transmitted by these two methods, are (as seen in a former chapter) nearly equal, it becomes at once apparent how important is the relation of form and the nearness of radiating surfaces to each other, as bearing on the total result.

The *outside* area of the sides, top, and base of any heater is virtually all the surface useful for radiation. Thus, in the radiator considered in diagram No. 16 (page 314), the total number of square feet of heating surface is 30; the dimensions, 4′ x 2′ x ½′; outside area, 2 (4 x 2 plus 4 x ½ plus 2 x ½) = 22 square feet. The ratio of the outside surface to the whole heating surface is about as 2 to 3, and the radiation per average foot of surface will be two thirds that of the horizontal pipe under similar conditions of temperature.

This is illustrated by diagrams Nos. 17 and 18, in which the blue lines show where such rays are arrested by other pipes and tubes; the red rays, by the same law and arrangement, escape into space, and reach the walls and furniture of the room,— it being understood that the red rays, so shown as passing from the hot surface, *do not warm the air through which they pass*, as air is only warmed by *actual contact with a heated surface.*

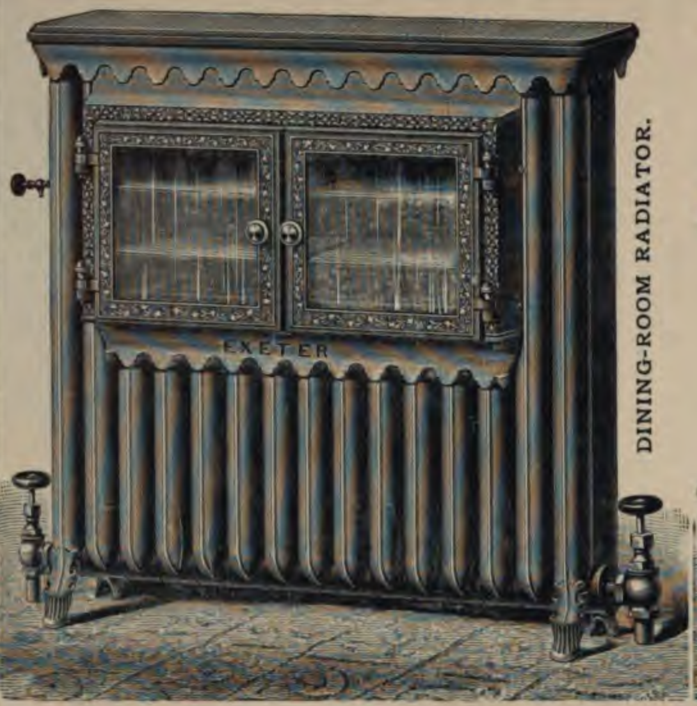
In the matter of our diagrams we do not claim that they are scientifically correct in every line, or that the total number of lines represent the total heat passed in any one case, but that practically they do so, and that all experiments combined on radiator surfaces show that our *mechanical* standpoint is correct.

Plate No. 32 shows a late form of the double-tube construction of the Exeter Machine Company. This plain yet neat design should make it a general favorite.

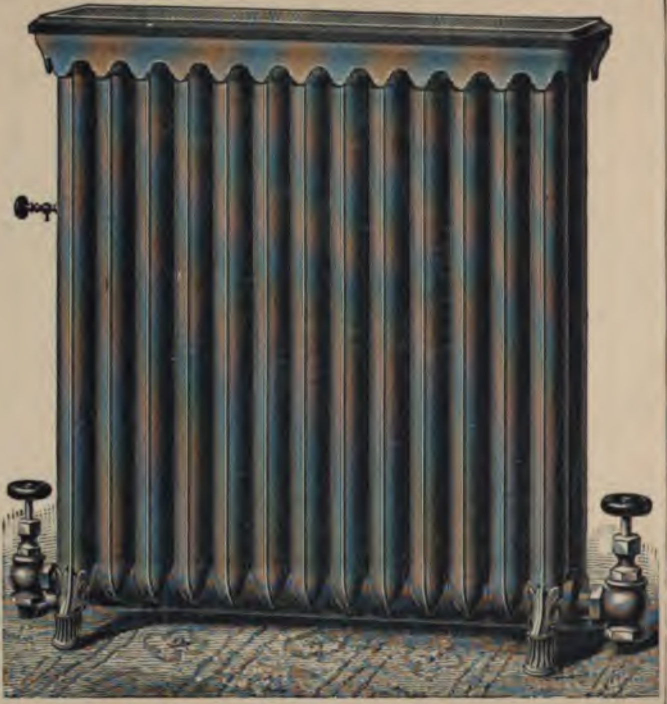
The dining-room radiator, shown on the same plate and by the same firm, presents a very good arrangement of this desirable adjunct to the dwelling where steam or water is the circulating medium. The carrying up of the end tubes on each side of the closet takes away the rather heavy and clumsy look of most other designs. This radiator has also the patented detachable leg, a decided improvement; as, should one become broken in handling, it can easily and cheaply be replaced. Besides, this allows elevation of the radiator to different heights, as is often desired under windows and in other recesses.

PLATE NO. 32.

NEW CAST-IRON DIRECT RADIATORS.



DINING-ROOM RADIATOR.



MANUFACTURED AND FOR SALE BY THE
EXETER MACHINE CO.,
51 Oliver and 245 Franklin Streets,
BOSTON, MASS.

For tests of efficiency,
see following tables,
No. 10 and No. 11,
Experiment No. 27.

In plate No. 33 is seen another example of a three-pipe radiator, the same that is compared in diagram No. 18, as the Elite and Triumph have the same sectional construction, differing only in finish and some other minor details.

It is claimed as an important feature of this radiator "that a large proportion of its heating lines are arcs of a parabola," and that, like the reflector behind a locomotive headlight, which throws its light rays into space, "so in like manner does this radiator discharge its heat units into the apartment to be warmed."

While this reference and illustration of the laws that govern heat and light as being one and the same is undoubtedly correct and in the line of our inquiry, the reference to a flame and a polished reflector does not seem to be quite in order when applied to dull heating surfaces, which, instead of being reflectors, are themselves the source of the heat rays.

These leave the surfaces heated from *within* and pass *outward* into space in lines whose intensity is proportional to the "sine of the angle of the ray with the surface," not from a light or source of heat outside and at a distance, but from every part of the hot surface, seeking a colder surface than itself. If there are no colder surfaces presented, there will be no radiant heat absorbed from the surfaces of the radiator.

It is only when the rays from a heated body are free to move away in straight lines and to a colder surface that any transfer of radiant heat takes place. See diagrams Nos. 17 and 18.

In the case of surfaces employed as radiators, we should consider the light as placed *within* the heated tube. Then, if such surface was perforated with minute holes, the light would stream out principally at right angles to the orifices. If there is no obstruction, then the light, or, in our case, the heat rays, will pass outward into space, or until absorbed by a cooler surface, and *regardless of the distances traversed*, their intensity being *inversely as the square of the distance between the source of heat and the absorber.*

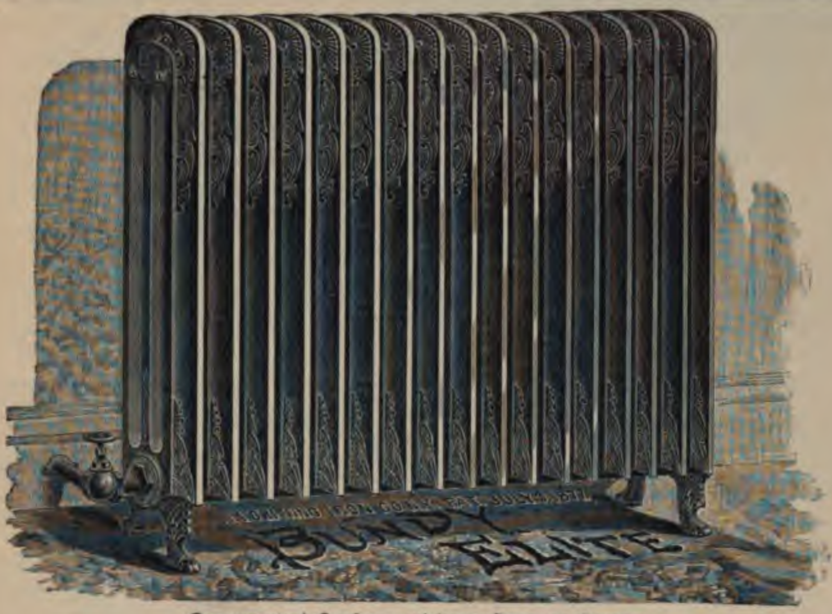
On the same plate, No. 33, is shown a dining-room radiator made by shortening the Bundy tubes. This is a very handy way of keeping food warm without sending it to the kitchen.

As far as heating and radiating surfaces are concerned, we are inclined to give preference to the "Bundy" lines, as more favorable to radiant heat than the later ones seen in the "Elite" or "Triumph" constructions.

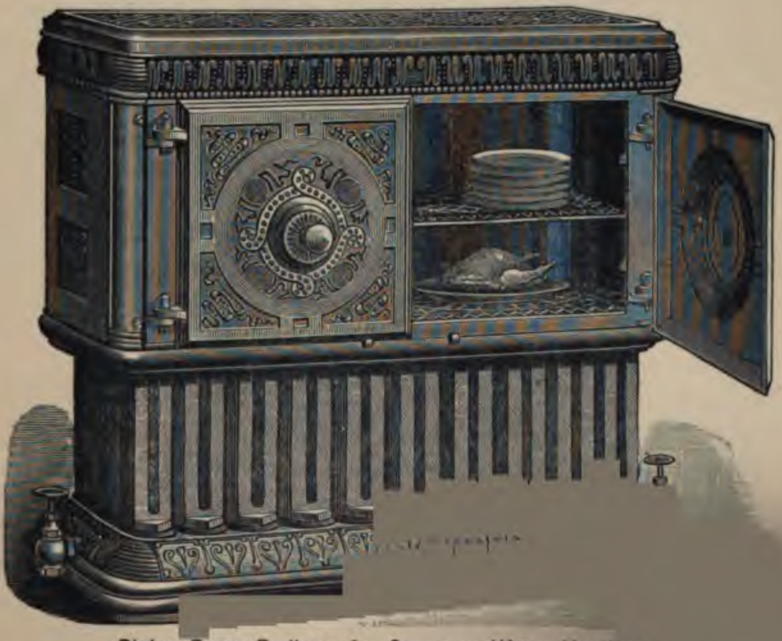
That the several radiators of the Griffing Iron Company are among the best devices of their class, may be inferred from the preferences given them by heating contractors and the trade. In the next chapter will be seen a radiator of the same firm for indirect heating or warming of air below the floors, and for either steam or water circulations.

PLATE No. 33.*

CAST-IRON DIRECT RADIATORS FOR STEAM OR WATER HEATING.



Ornamented Surface, without Base or Screen.



Dining-Room Radiator for Steam or Water Heating.

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* A. A. Griffing Iron Co., Jersey City, N. J.

In plate No. 34 we have a view of a farther advance in the line of cast-metal construction. This is seen in a *quadruple-pipe* sectional radiator, intended for either a steam or a water circulation, and for the latter is provided with an opening and supply pipe entering the radiator at the top; this flow pipe is also provided with a neat and serviceable valve for controlling the flow, and thus the temperature of the water.

The lines employed in the outer row of pipes are concavo-convex, and are thus more favorable than those which are entirely concave, or even parallel, as seen in some older designs. That the inside rows are somewhat shut in, is perhaps true, also that the general laws relating to *massed surfaces* must also obtain in this construction; yet, as there is no reliable test reported and the manufacturers have not yet *marked the surface up*, we do not know how high it will eventually stand in the scale of practical efficiency.

The absence of any obstructing base will help to counteract an otherwise unfavorable relation of the *inside* surfaces; the pipes are generally harmonious and quite profusely ornamented, and should satisfy the strongest craving in that direction.

When the totality of all the heat that is radiated is considered, taking into account not only the rays perpendicular to the surface which represent the principal radiation, but also the oblique rays of less intensity, the reduction in value of concave and parallel surface is more apparent, since it is the oblique rays that are more largely cut off and intercepted by the other heated surfaces.

As further referring to the omission of the screen cap and ornamentation of the tubes in quite a number of direct radiators, we may say that the Union (Plate No. 31) is now being fitted to meet this demand, and that in the new dress it will be known as the *Royal Union*.* In this connection it is safe to say that in all probability it will require the screen cap and also the legs to make up the square feet of heating surface credited to many of the cast-metal direct radiators. Still, the removal of the screen will not weaken, but rather increase, the final duty, as permitting the circulation of the air over the tubes. It is, however, clear, that this matter of ornamentation on the already heavy construction of radiators can be overdone, and the reverse of what is desired obtained, since it is clear that no possible form of an iron radiator can be made to contribute to the harmony of an otherwise well-proportioned and appointed room.

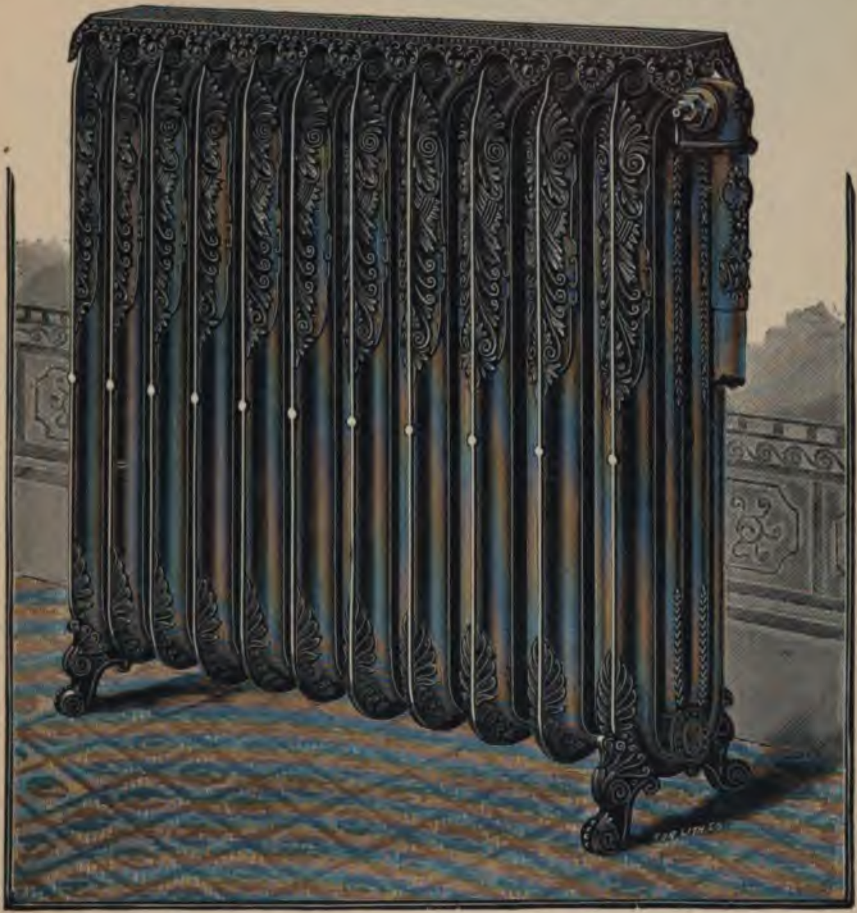
Instead of calling attention to this substitute for the always unsightly stove, the radiator should be retired as much as possible. Sometimes this good taste prevails, and where the heaters are not placed below the first floor they are let into recesses made for them under the windows, or, what is still better, into a space formed in the breast of the chimney.

* See Chapter XXV.

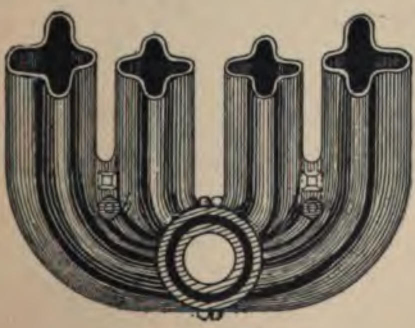
PLATE No. 34.

NEW CAST-IRON WATER RADIATOR.

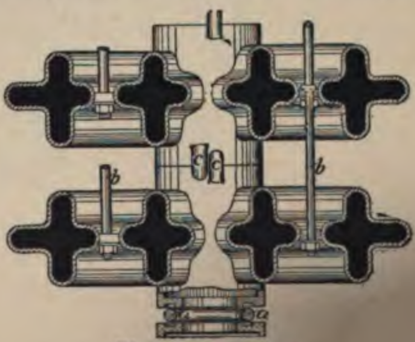
GURNEY WATER HEATER CO., 237 FRANKLIN ST., BOSTON.



Quadruple Pipe Sections. Standard Height 39 Inches.

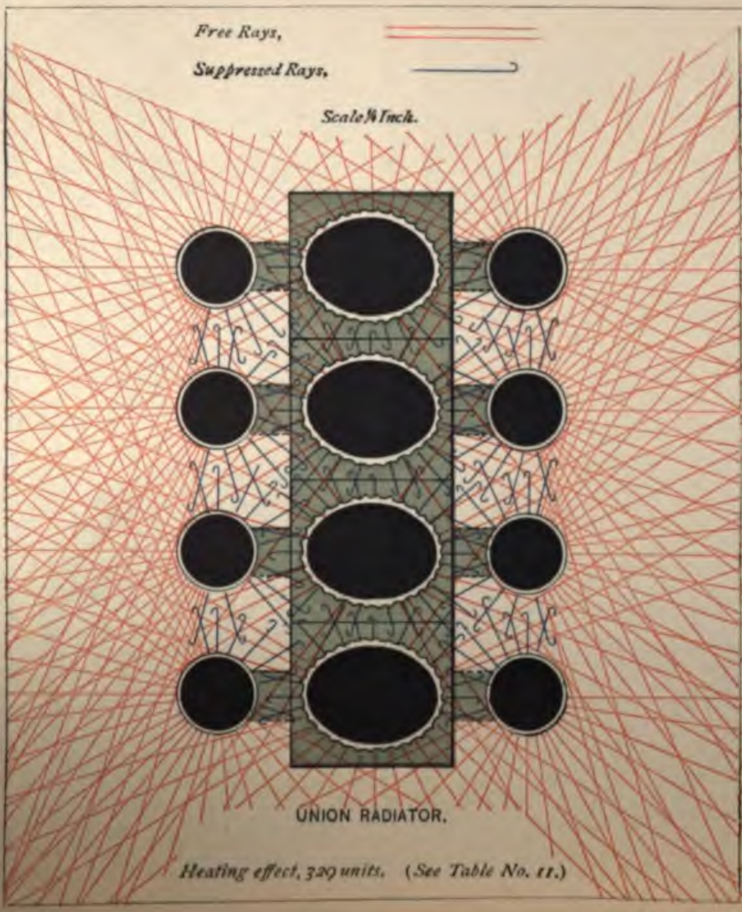


Sectional elevation.



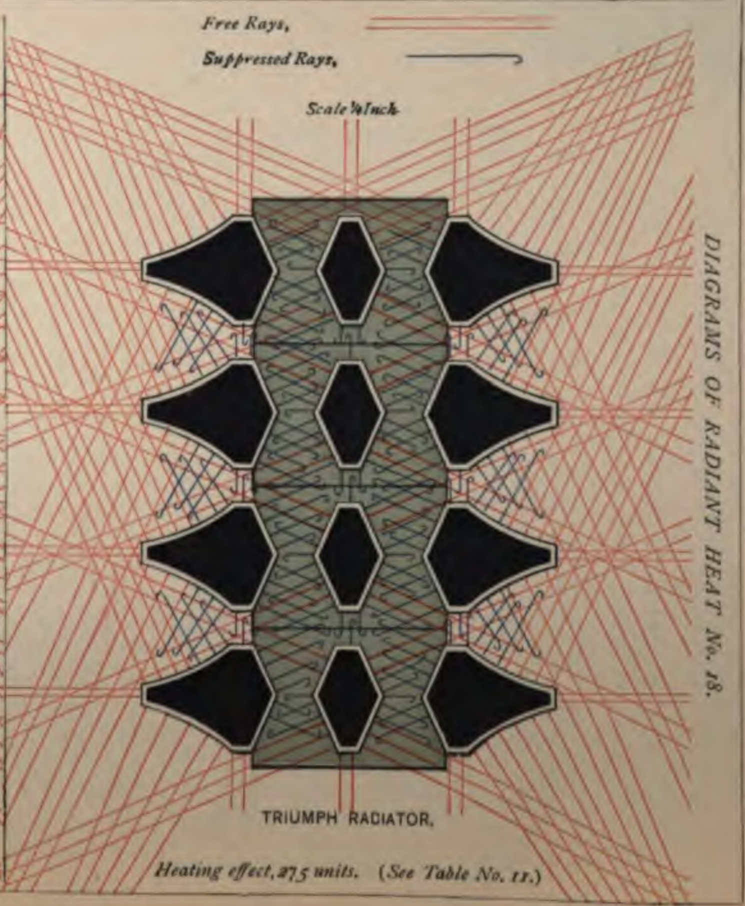
Plan and section.

DIAGRAMS OF RADIANT HEAT No. 18.



UNION RADIATOR.

Heating effect, 329 units. (See Table No. 11.)



TRIUMPH RADIATOR.

Heating effect, 275 units. (See Table No. 11.)

CHAPTER XX

INDIRECT HEATING SURFACES.

THE heat of *indirect* radiators is given out mainly *to the air by contact or conduction*, and not to any extent *by radiation*. Heat by radiation requires a cooler object, to which the rays of heat may pass; but, in the case of an *indirect* radiator, enclosed in a wooden box or other casing, the greater part of the surface is surrounded by other surfaces of the radiator at the same temperature, and the only heat by radiation is from the side of the stack to the metallic lining of the box, and, as this has nearly as high a temperature as the surface itself, it receives and parts with but little heat.

In an indirect heating chamber the cold air enters at the base, and passes off at the top, becoming more and more heated as it rises. The temperature finally attained at its exit depends on several conditions.

1st. The temperature of the air entering the radiators and that of the heating medium within them. 2d. The rapidity with which the air passes through, or the volume supplied. 3d. The height of the radiator, which determines how long the air is in contact with the heated surface, when it passes vertically through it. 4th. The closeness of the contact of the air with the surfaces, dependent on the internal construction.

When air is passed over a heated surface, the amount of heat that it abstracts varies with the velocity of its motion, according to a certain law that depends on the form of the surface, and therefore differs with each construction.

The complexity of the law does not admit of any simple statement; but it may be illustrated graphically by means of curves, which represent to the eye the relations between the heat and the air.*

The amount of heat that will be transmitted also depends on the relative temperatures of the cold air admitted and that of the surface which conveys the heat. It was formerly supposed to increase in exact proportion to the increase of t[illegible]ure in the radiator; but it is evident, from more exact [illegible]e results of practice in heating, that this would [illegible]

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* Se [illegible]

The following is the more exact law: —

The heat given off by any body to the air in contact with it in a given time, is proportional to the 1.23 power of the excess of the temperature of the surface over that of the air.

Thus, following the course of the ascending current through the radiator, it is evident that when the cold air first meets the surface of the heated metal the amount of heat absorbed is the greatest; if the difference in temperatures is 180°, the heat abstracted and absorbed by the air will be proportional to the 1.23 power of 180, or to the number 594.

When the air has risen a little and become heated 1°, the excess of temperature is only 179°, and the efficiency of the radiator at this point is represented by the same power of 179, or by the number 590.

Thus, the amount of heat taken up by the air decreases, until at the top of the radiator, where the air makes its exit, supposing it has been warmed, say, 100°, the difference between the temperatures is only 80°, and the demand on the surface for heat is proportional to $80^{1.23}$, or the number 219,— about 37 per cent of the heat received at entrance.

It is thus apparent that by increasing the depth of the radiator beyond a certain point, the added surface becomes inoperative, only serving to raise the temperature of the heated air a few degrees.

A depth of six inches has been found sufficient in cast-iron radiators with extended surface, as the Gold's pin and other similar heaters, to meet the demands of the average American climate.

An instance illustrating the uselessness of excessive depth is shown in the table relating to the reconstruction of the heating apparatus at the Buffalo State Insane Asylum.[*]

Here the radiators were originally set in double tiers, through both of which the air was obliged to pass; the removal of one tier of radiators throughout the building resulted in a gain in the general efficiency, and, as shown, there was still a reserve of one third of the whole surface throughout the winter.

To what degree is the temperature of the heated air altered when the heat in the medium is increased, or the temperature of the *entering* air falls?

This question has been experimentally investigated by Mr. C. B. Richards, at the Springfield Armory, a report of whose tests is given in Johnson's Cyclopaedia, Vol. IV. The conclusions are expressed in the following law, and shown by table No. 11½.

"*The heat that an indirect radiator yields to the air varies directly with the difference of the temperature of the steam in the heater and that of the cold air when it first strikes the heating surface.*"

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[*] Page 119.

TABLE No. 11½.

Degrees Air is Warmed by Indirect Radiators (Uniform Air Supply).

Temperature of the Entering Air, 70° above to 20° below Zero. Of the Radiator, 150° to 300° Fahr.

Difference between Temperature of Radiator and Entering Air.

°	Increase in Temperature of the Air Passing through the Radiator.																			
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
300	240	230	220	210	200	190	180	170	160	150	140	130	120	110	100	90	80	70	60	50
290	232	222	213	203	193	184	174	164	155	145	135	126	116	106	97	87	77	68	58	48
280	224	215	205	196	187	177	168	159	149	140	131	121	112	103	93	84	75	65	56	47
270	216	207	198	189	180	171	162	153	144	135	126	117	108	99	90	81	72	63	54	45
260	208	199	191	182	173	165	156	147	139	130	121	113	104	95	87	78	69	61	52	43
250	200	192	183	175	167	158	150	142	133	125	117	108	100	92	83	75	67	58	50	42
240	192	184	176	168	160	152	144	136	128	120	112	104	†96	88	80	72	64	56	48	40
230	184	176	169	161	153	146	138	130	123	115	107	100	92	84	77	69	61	54	46	38
220	176	169	161	154	147	139	132	125	117	110	103	95	88	81	73	66	59	51	44	37
210	168	161	154	147	140	133	126	119	112	105	98	91	84	77	70	63	56	49	42	35
200	160	153	147	140	133	127	120	113	107	100	93	87	80	73	67	60	53	47	40	33
190	152	146	139	133	127	120	114	108	101	95	89	82	76	70	63	57	51	44	38	32
180	144	138	132	126	120	114	108	102	96	90	84	78	72	66	60	54	48	42	36	30
170	136	130	125	119	113	108	102	96	91	85	79	74	*68	62	57	51	45	40	34	28
160	128	123	117	112	107	101	96	91	85	80	75	69	64	59	53	48	43	37	32	27
150	120	115	110	105	100	95	90	85	80	75	70	65	60	55	50	45	40	35	30	25
140	112	107	103	98	93	89	84	79	75	70	65	61	56	51	47	42	37	33	28	23
130	104	100	95	91	87	82	78	74	69	65	61	56	52	48	43	39	35	30	26	22
120	96	92	88	84	80	76	72	68	64	60	56	52	48	44	40	36	32	28	24	20
110	88	84	81	77	73	70	66	62	59	55	51	48	44	40	37	33	29	26	22	18
100	80	77	73	70	67	63	60	57	53	50	47	43	40	37	33	30	27	23	20	17
90	72	69	66	63	60	57	54	51	48	45	42	39	36	33	30	27	24	21	18	15
80	64	61	59	56	53	51	48	45	43	40	37	35	32	29	27	24	21	19	16	13
70	56	54	51	49	47	44	42	40	37	35	33	30	28	26	23	21	19	16	14	12
60	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10
50	40	38	37	35	33	32	30	28	27	25	23	22	20	18	17	15	13	12	10	8
40	32	31	29	28	27	25	24	23	21	20	19	17	16	15	13	12	11	9	8	7
30	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5

Example 1st. The difference between the temperature of the radiator and that of the entering air is 170°, and the air is warmed 68°. How many degrees would the air be warmed if the difference between the temperatures is 240°?

The radiator column corresponding to 170° difference of temperatures and 68° increase in temperature is M (Table *). The number of degrees that the air is warmed, col. M, for difference 240°, is 96 (Table †).

Example 2d. *The effect of changes in the temperature of the heating surface of the radiator.*

If, with the radiator at 150°, air entering is warmed from 70° to 131°, to what temperature will it be warmed when the radiator is at 260°?

Radiator column corresponding to 150° — 70° = 80° difference, and 131° — 70° = 61° increase, is B. The number of degrees that the air is warmed for 260° — 70° = 190° difference (Col. B) is 146. Hence the required temperature of the air leaving the radiator is 146° + 70° = 216°.

Example 3d. *The effect of changes in the temperature of the air admitted to the radiator.*

Radiator, 212°; air admitted at 62° is warmed 80°. To what temperature would it be warmed if the air entering is at zero?

Radiator column corresponding to difference 150°, increase 80°, is I. The number of degrees that the air is warmed for 212° — 0° = 212° difference, col. I, is (approximately) 112°. Hence the required temperature of the warm air is 112° + 0° = 112°.

Example 4th. *Conditions for uniform temperature of the air warmed.*

Radiator at 215°, air entering 5 [illegible]ator 162°. What must be the temperature of the radiator in order that [illegible] at zero the warm air is still 162°?

Radiator column for 215° — [illegible] 162° — 55° = 107° increase, is E. The difference correspond [illegible]ase (col. E) is 240°, and 240° — 0° = 240° is the required [illegible]

In the following plate, No. 35, is seen the oldest, and we may say the best, forms and arrangements in cast-iron *indirect heaters*. We use the word "*heater*" here intentionally, as the designation "radiators" does not properly apply to heating devices that are not in the rooms to be warmed, but in boxes or chambers below the floor, and rely solely upon their power of warming the air by contact with their hot surfaces.

This matter was treated somewhat at length in a former chapter, and was fully illustrated by diagram 16 and table 9, and will be again referred to later, when considering the methods of heat transmission.

The middle "heater" B is the celebrated Gold's pin extended surface, invented by Samuel Gold and put into practical use in 1862, and thus may stand as the earliest device for warming rooms in dwelling-houses by the "indirect" warming of the outside air, which is then sent to the rooms through tin pipes and registers.

As we have before stated, this proved, not only the most efficient indirect heating surface ever produced, but it embodied those sanitary conditions of warmth and ventilation of homes not before attempted, and not since excelled by later inventions.

Still, it was a long, long time before the trade learned to estimate the Gold's pin radiator at its full value. A single bar of the standard pattern did not measure but eight and five-eighths feet, and yet setting it up alone it proved equal to any ten feet of pipe or other heating surfaces, at which it has always been rated.*

Letter A of the same plate shows another form of extended indirect heating surface, the Whittier, which at the time (1871) it was supposed would take the place or answer the same purposes as the Gold's pin. This, however, was not the case, as the flat form of teeth was not so favorable for the conduction of the heat of the body plate to the rim of the tooth, and even with greater depth there was not as much air warmed or to as high a temperature.

This form of tooth was later put into a direct radiator, and has, owing to favorable construction of bar, giving a positive return bend circulation, been very much used, both for steam and water; the main drawback being, as now readily seen, a serious loss of efficiency in the line of *direct radiation;* the flat teeth, standing close and nearly parallel to each other, give out almost no direct heat rays, the final loss amounting to over 25 per cent. The lower figure C, same plate, shows another and more favorable heating section for indirect air warming; the teeth or ribs not standing so near together, more of the original plate is available, while the positive circulation accomplished by this method of joining contributes to the higher duty obtained.

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* See table No. 11, experiments Nos. 24 and 25. † Whittier patent, 1873.

PLATE No. 35.

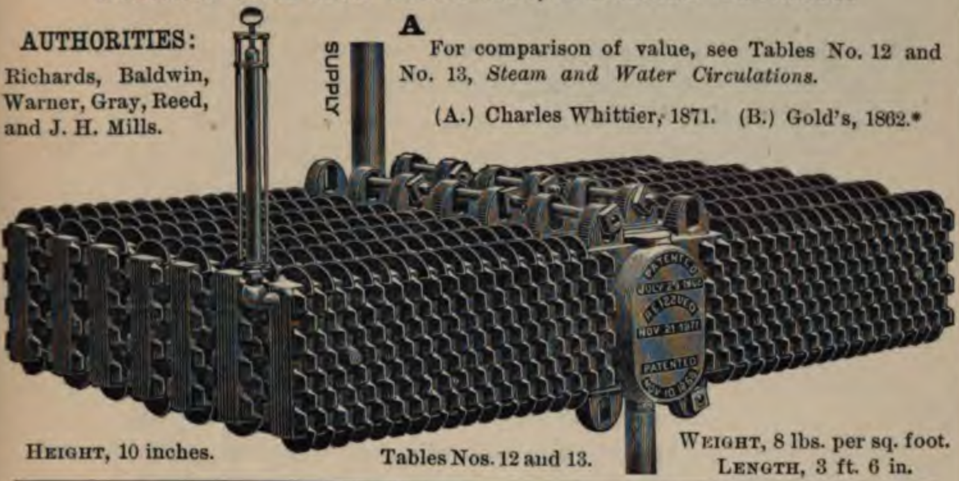
Indirect Cast-Iron Radiators, Extended Surfaces.

AUTHORITIES:
Richards, Baldwin, Warner, Gray, Reed, and J. H. Mills.

A

For comparison of value, see Tables No. 12 and No. 13, *Steam and Water Circulations.*

(A.) Charles Whittier, 1871. (B.) Gold's, 1862.*

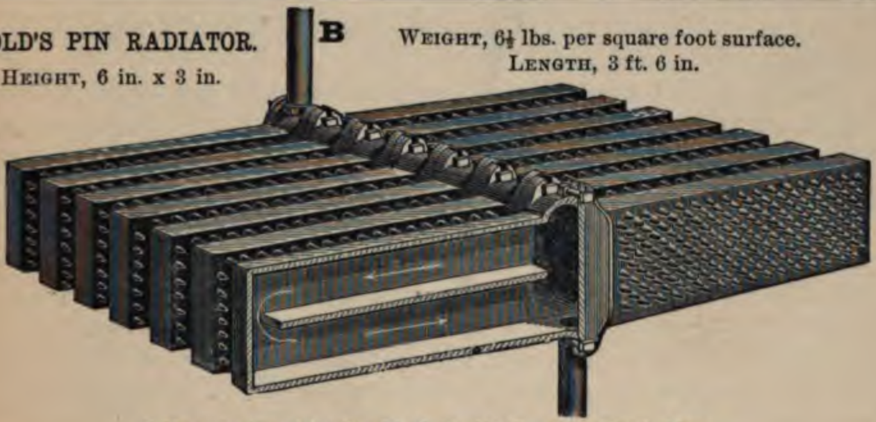


HEIGHT, 10 inches. Tables Nos. 12 and 13. WEIGHT, 8 lbs. per sq. foot. LENGTH, 3 ft. 6 in.

B

GOLD'S PIN RADIATOR.
HEIGHT, 6 in. x 3 in.

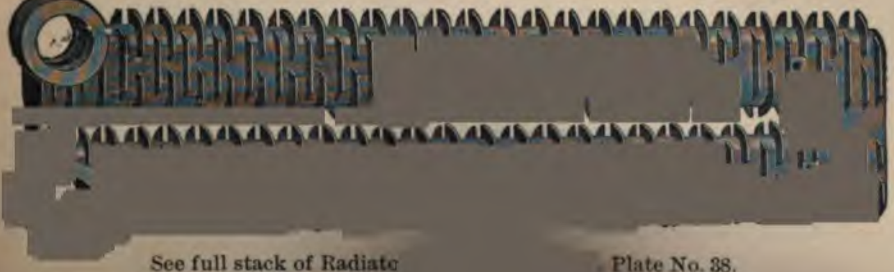
WEIGHT, 6½ lbs. per square foot surface.
LENGTH, 3 ft. 6 in.



* Manufactured by the H. B. Smith Co., Westfield, Mass.

C

† CLIMAX INDIRECT RADIATOR.
FOR STEAM OR WATER CIRCULATIONS.
Length, 3 feet; Height, 11 inches; Width, 3½ inches.



See full stack of Radiat [illegible] Plate No. 38.
† Manufactured by the A. A [illegible] sey City, N. J.

Plates Nos. 36 and 37 illustrate the axiom before stated, that the depth of the heating or pipe surface over which the air may pass has little to do with the efficiency or total work accomplished. They also show that it is a *close contact of the air with a heated surface*, rather than a great height, that renders the heater more powerful and certain to do the required work.

In figure 1, we see that eight pipes high in a plain box coil would not raise the temperature of a given body of air so high as the two pipes high in the other figure wound with spiral wire, and also that the whole work of the box coil was less with three times the pipe surface.

Plate No. 37 shows an enlarged view of the wire-treated pipe, and also a view of the combined surfaces as made up into heaters.

This is a clear case of *conduction and radiation;* the wire, touching the heated surfaces only at intervals and with the smallest possible contact, is still heated mainly by radiation; the hot rays, passing outwards, are intercepted by the wire coil, which in turn heats the air brought intimately in contact and with greatly increased surface, so that this auxiliary surface is little less powerful than the original pipe containing the live steam.

This compound heating surface took engineers by surprise, as well it might. The writer, even while well acquainted with the superior power and value of the extended surfaces (patented by the father of this invention), could not at first credit the statements made of the work done by these compound coils. They were, however, tested by that practical engineer, W. J. Baldwin, in 1885, and by the writer later at Buffalo, when he found that the former tests were substantially as stated; viz., that 60 feet of this compound coil, made up of one-third wrought-iron pipe and two-thirds wire tested with 60 feet of the original Gold's pin radiator, gave 690 units of heat per rated square foot of surface per hour, with an air supply of 300 cubic feet of air, temperature of 82° Fahr.*

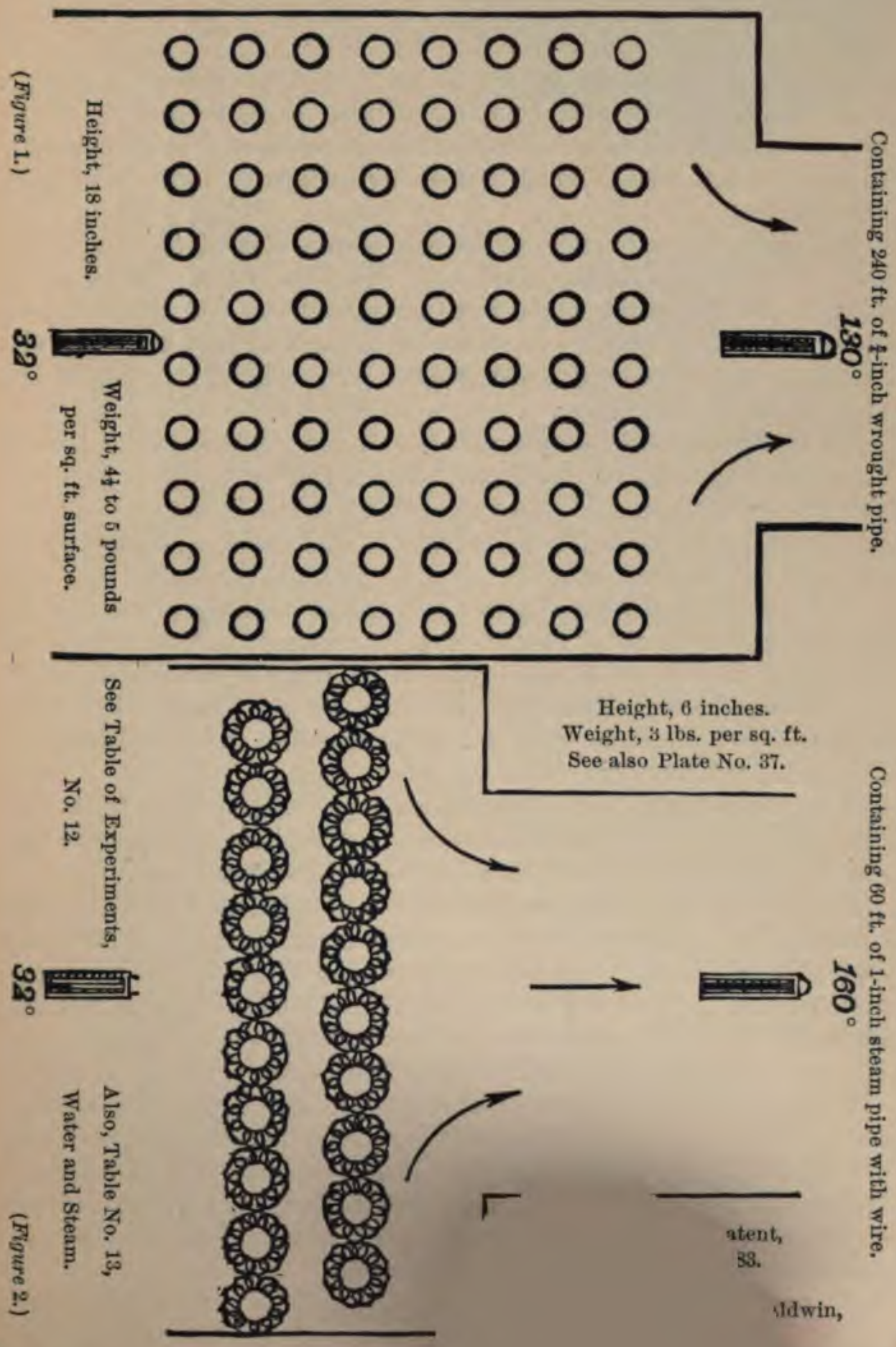
It is thus seen how little of the real facts of the true value of any heating surface can be learned by simply looking at it, and then forming a judgment based on an entirely different surface and condition.

The winding of coils of No. 14 square wire, of strong elastic tension, around one-inch pipes of common return bend coils (two pipes high) constitutes the main feature of this invention; while enclosing the same in substantial casings, lined with tin, which serves both for shipping and for the final adjustment of these stacks beneath the hot-air pipes and registers, simplifies the almost endless details of steam and hot-water heating construction. The plan combines compactness, lightness, strength, rapidity of circulation, durability, and economy of time and labor in their erection.

* See tables No. 9 and No. 13.

PLATE No. 36.

Experiments with Plain Pipe in Box Coils and Gold's Compound Coil Radiators.


Containing 240 ft. of ¾-inch wrought pipe.
130°
32°
Containing 60 ft. of 1-inch steam pipe with wire.
160°
32°
Height, 6 inches.
Weight, 3 lbs. per sq. ft.
See also Plate No. 37.
atent,
83.
ldwin,

(*Figure* 1.)

Height, 18 inches.

Weight, 4¾ to 5 pounds per sq. ft. surface.

See Table of Experiments, No. 12.

Also, Table No. 13, Water and Steam.

(*Figure* 2.)

[*] This auxiliary surface adds to the advantages above enumerated *great heating power*, as it is impossible for a volume of air to pass through this heater without being completely and promptly warmed, as the main current is broken into innumerable smaller currents by means of the hot coils.

In indirect steam heating, one linear foot of one-inch pipe, coiled with wire, is equal in heating power to *three and three-tenths* lineal feet of one-inch pipe; while in hot-water heating, one lineal foot of one-inch pipe, coiled with wire, is equal to *three and seven-tenths* lineal feet plain one-inch pipe.

The difference in the relative heating powers of one-inch compound coil and plain-pipe surface, when steam is used and when hot water is used, is probably owing to the fact that in hot-water heating the circulation is checked more by friction than in steam. In the compound coil the steam or hot water makes but one turn, while in plain-pipe coils eight or ten turns are made.

The air supply for indirect radiators is generally at a much lower temperature than that for the direct, being drawn from outside and let into the stack, whence it is drawn through the heated chambers either by the suction of the ascending column of heated air, or impelled by a fan and mechanical appliances.

The increase of the heat given out, due to the temperature of the entering air being at 32° instead of at 70°, is, by table No.11½ for pipe coil about 28 per cent. This gain in efficiency is counterbalanced by the almost total absence of radiation; the tin lining of the box containing the stack being at a high temperature, but little heat is transferred to it from the stack.

If in an indirect stack of radiators a larger volume of air is blown through the openings between the heated surfaces, they will tend to be cooled more rapidly, and so give off a greater amount of heat.

For low-pressure steam or hot-water circulation and a difference between the temperatures of the entering air and the pipes of 196°, an *average of results with different radiators gives* 277, 411, 565, 697 heat units per foot per hour respectively for, 118, 210, 326, 419 cubic feet of air supplied per foot or surface per hour (table No. 12, columns I and N), or an average of 1½ units per cubic foot additional air passed.

When the pressure in the pipes is increased, the temperature of the steam rises also; an average rise of 2° per pound pressure additional for the first 35 pounds, 1° for the next 35, and so on (table No. 14, column B); and, as the pipe or radiator has about the temperature of the steam or hot water within it, more heat is given out by the hotter surface corresponding to the temperature of the steam.

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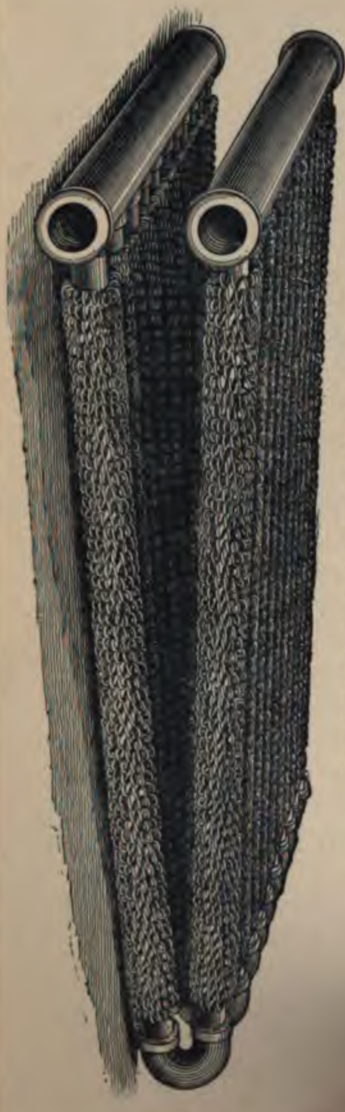
[*] Extracts from Gold's circular.

PLATE No. 37.

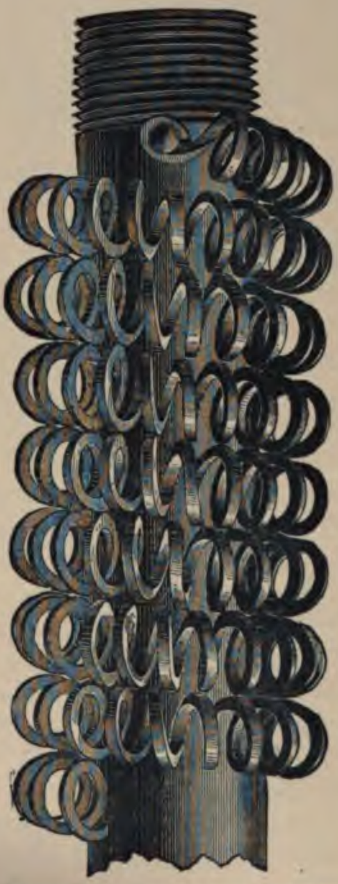
DETAILS OF WROUGHT-IRON PIPE WITH EXTENDED SURFACES.

Gold's Compound Coil and Pipe Surfaces shown in Plate No. 36.

These two cuts also illustrate the general difference in construction, operation, and results between Cast-Iron INDIRECT Radiators and Pipe Surfaces in Compound Coils.



View of Radiator used in experiments with Plain Pipe in Plate No. 36.
See also experiments with Water, Table No. 13.



Enlarged section of pipe and wire employed in constructing coils shown [illegible] No. 2, plate No. 36. See [illegible] No. 12, Baldwin's experi[illegible]nd 25.

Plate No. 38 shows a full stack of the Climax heating surface in its casing, with a cold-air supply and warm-air delivery to the rooms above.

The writer has not personally made any experiments with this particular heater, but from such data as was obtained by the Griffing Iron Company the surface stands for the same air and average conditions: for the Climax, 815 units; Gold pin, 866 units; wrought-iron return bend radiator, 766 units per square foot per hour.

While these are the common and desirable arrangements, it is seldom that they are practically carried out, and the stack properly suspended, with room above and below for the entrance of the cold, and delivery of the warm, air.

The cold air is entered at the opposite end from where the warm air is taken away; the top of the casing is pitched to the delivery, which is, as it should be in every case, above the floor, *not through it;* as besides freeing the floor and carpets of an objectionable opening, there is a positive gain in the work of the whole stack, due to the increased height of the warm-air delivery; the power in all of these cases being as the square root of the height of the confined warm-air column.

Although this mode of delivery of warm air and location of register is well known to heating engineers, the architects and owners are slow to understand its plain and decided advantages. That somewhat common trouble, a reversed circulation or stagnation of the warm-air delivery, is not likely to occur with a *side* register, neither is the stack liable to be filled up with chips and all sorts of dirt during the construction of the building; as, owing to the nature of the surfaces, it is almost impossible to remove the accumulated filth that is sure to be thrown into such inviting openings. The only efficient remedy for this unnecessary evil is to burn the stack out before the dwelling is occupied. On the same plate, letter B, is seen the arrangements of the Griffing Company for introducing fresh air in connection with a direct radiator.

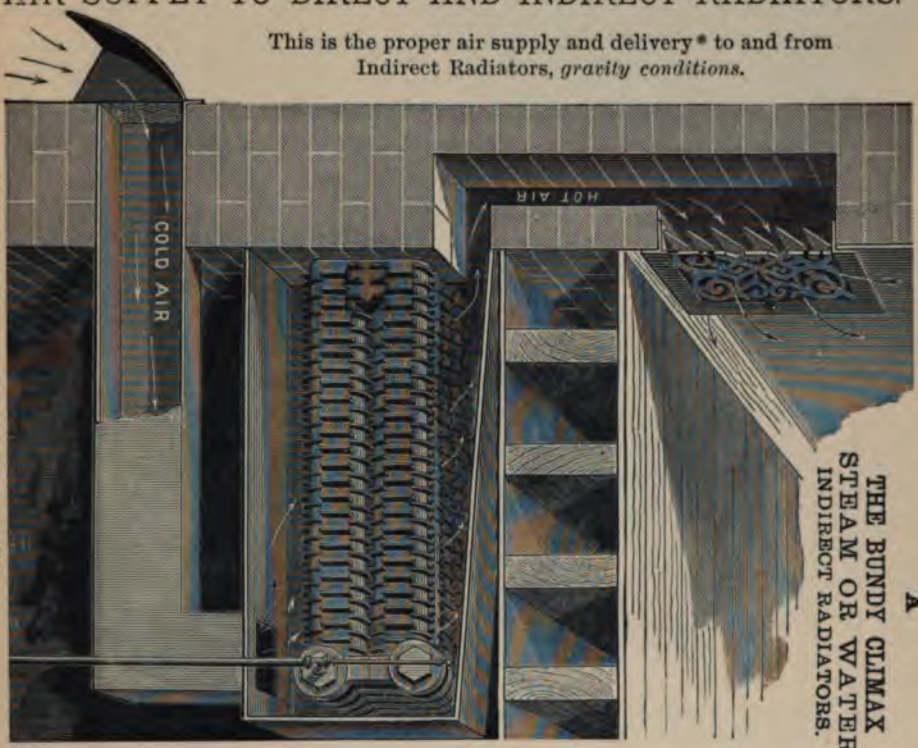
The lower cut (B) on the same plate shows how fresh-air inlets may be best arranged for *direct radiators.* There are other ways for admitting air without as much cutting and hooding as shown. One is to avail of the space generally left below the stone window sill; then by conducting the air back of a partition behind the radiator, it may answer every purpose of the more elaborate and expensive plan.

That radiators placed in rooms and simply warming the same air over and over again have really no sanitary advantages over the furnace, is now quite generally understood, and several devices have been attempted for securing a supply of air in the above simple way. The fresh-air inlets and means for controlling the entering air are the main difficulty, and often cannot be had without coöperation with the architect when the building is in process of erection.

PLATE No. 38.

AIR SUPPLY TO DIRECT AND INDIRECT RADIATORS.

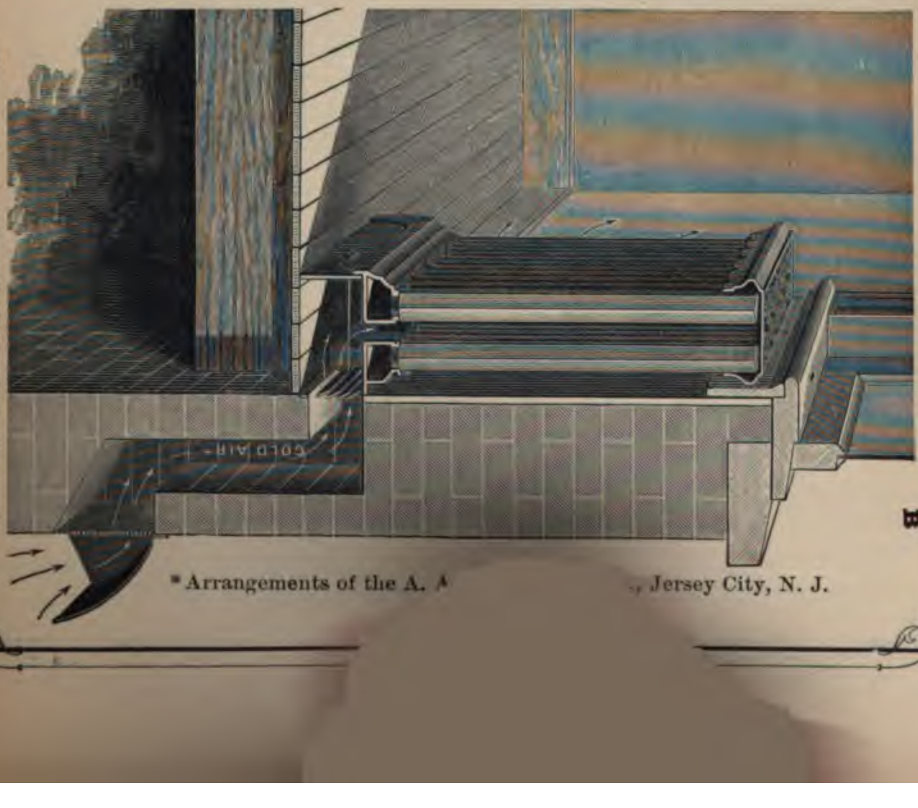
This is the proper air supply and delivery* to and from Indirect Radiators, *gravity conditions.*



A

THE BUNDY CLIMAX STEAM OR WATER INDIRECT RADIATORS.

Casing of Asbestos Board lined with Tin.



B

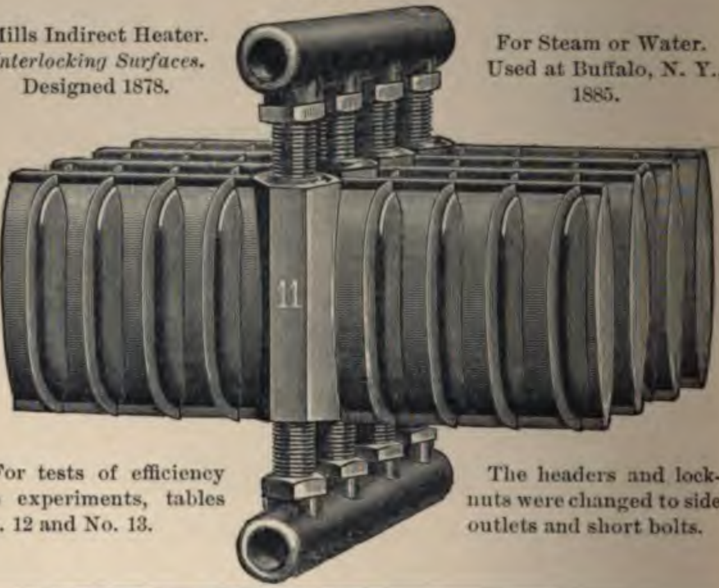
Regular Bundy Direct Radiator, with air supply.

* Arrangements of the A. A [illegible], Jersey City, N. J.

There has been much effort to construct and arrange plain cast-iron or wrought-iron pipe surfaces for indirect heating.

This cut shows a group of cast-iron chambers connected by header or branch tees. The pockets interlocking bring the surface quite near together, and with a depth of nine inches. The air was warmed to about the same temperatures as the Gold's Pin radiator. See table No. 12, page 367, experiments 7, 8, and 9, in which we find efficiencies for Gold's Pin 314, Walworth 316, Mills 385.

FIGURE 19.

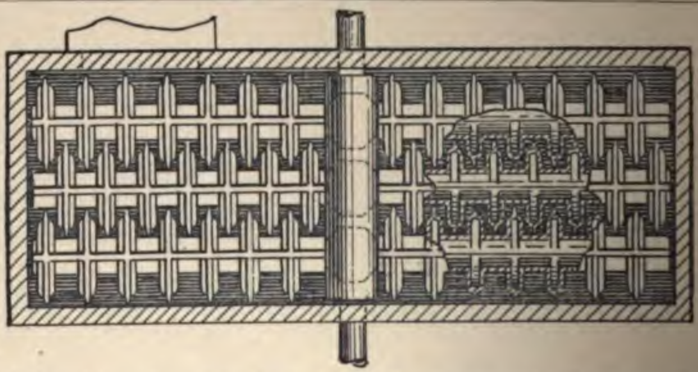


Mills Indirect Heater.
Interlocking Surfaces.
Designed 1878.

For Steam or Water.
Used at Buffalo, N. Y.,
1885.

For tests of efficiency see experiments, tables No. 12 and No. 13.

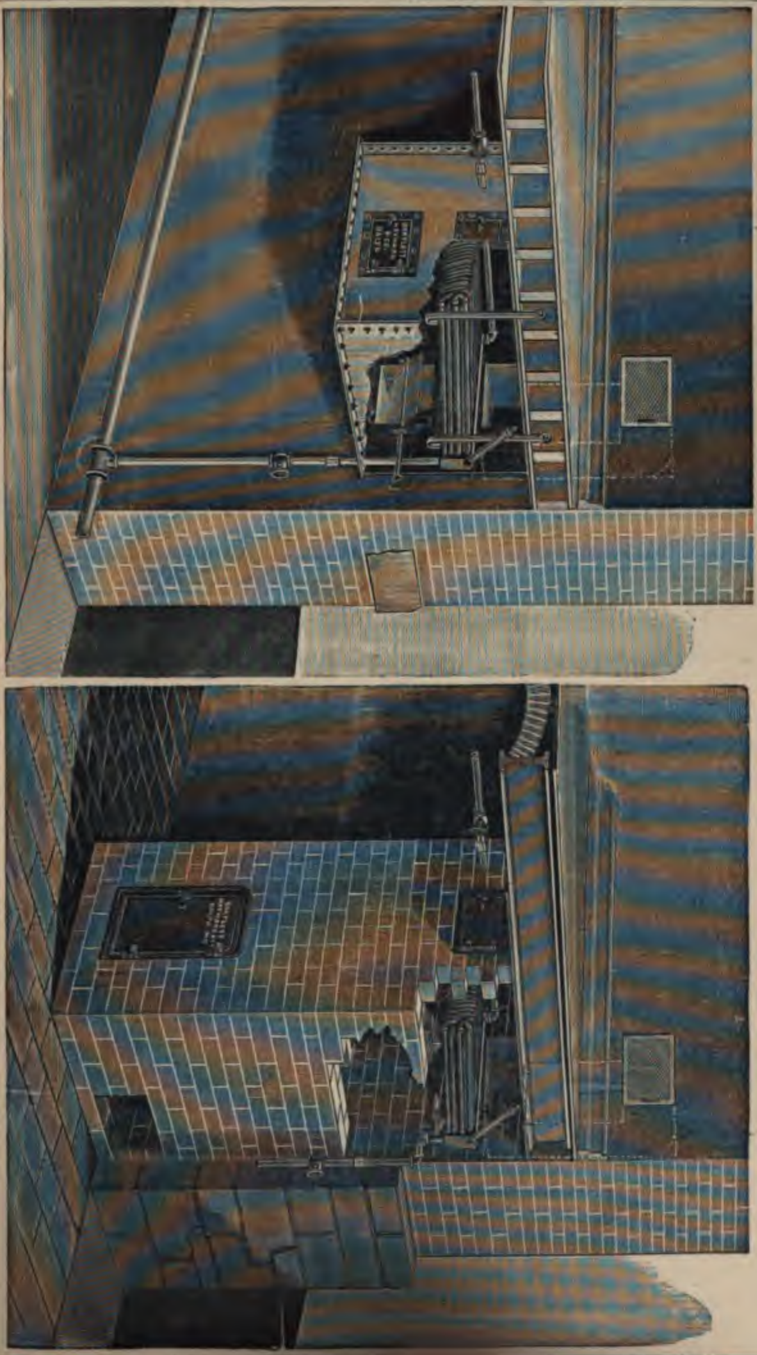
The headers and lock-nuts were changed to side outlets and short bolts.



The following plate, No. 39, shows further methods of constructing indirect heating surfaces in the basement, also two kinds of chambers for enclosing the same; where the floor space is not required for other purposes, the brick chamber is preferable, as less heat is conducted through the brick walls than through boxes having iron sides.

PLATE No. 39.

CASING OF GAL. IRON AND BRICK SETTING FOR INDIRECT STEAM RADIATORS.*



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* From Circular of Bartlett & H[illegible] Baltimore, Md.

EXPLANATION OF TABLE No. 12.

Table No. 12 is, as seen, the *experimental* result obtained from many indirect heating surfaces under the various conditions to which such "radiators" have been or may be employed in practice.

In compiling and arranging the work in the table, the *actual results obtained* by each experimenter are stated under columns A, B, C, D, E, and H. Where the air reported did not agree with the amount due to the heat actually surrendered (column H), it has been corrected, and is shown by column I.

The experiments are, as seen, arranged in the order of the amounts of air supplied and passed over each stack, and are stated in column I, as *per square foot per hour.*

Assuming that one unit of heat will raise the temperature of 52 cubic feet of air at standard density (.0807, or that due to a temperature of 32° Fahr.) 1°, the whole amount of heat transmitted to the air is first ascertained by weighing the products of condensation of the steam (one pound of steam condensed being equivalent to 1,000 units of heat). This, multiplied by the number fifty-two, is the cubic feet of air that would be raised 1° by the heat actually absorbed by the air. Finally, dividing by the number of degrees that the air is warmed in passing through the radiator, as ascertained by a thermometer placed at the entrance and the exit (values of which are given in columns D and E), the total number of cubic feet of air that has been warmed is obtained.

The amount of air that is passed practically determines the efficiency of the radiator; also, the same radiator, differently set, will pass very different amounts of air, the duty, as shown in columns L and M, varying correspondingly.

It is evident that the draught of heated air through radiators is as variable as through chimneys, being for the same flue sometimes good and at other times poor, due to the conditions of temperature, etc.

The table shows that the work of a square foot of indirect heating surface is nearly in proportion to the air passed over it in a given time, and that a foot of *indirect* radiator under its lowest duty and rating is equal to a foot of *direct* radiators standing in the rooms to be warmed.

Column J shows the cubic feet of air corresponding to an increase in temperature of 100°; while K and L are the units of heat also resulting from H; the final column, M, being the total heat resulting if each radiator had been *tested under the same temperatures of steam and air.*

By this final column we also see how nearly uniform are the results obtained by different experimenters and radiators when under the same conditions of air and steam. We note, however, one exception, that all of Richard's results with the Gold's pin radiator are higher than those of any other engineer; also, that, while the air was stated, the water of condensation was not given, *but is calculated from the total heat surrendered.*

TABLE No. 12.

**periments on *Indirect* Radiators selected from 200 Tests, with 15 different
adiators. Results reduced to Air at 32° and Steam at 5 lbs. (Col. M.)**

AMES OF RADIATORS, ENGINEERS, AND TES OF EXPERIMENTS.		Square Feet Surface.	Gauge Pressure, Steam.	TEMPERATURES.			DIFF. TEMP		Oz. Water Cond. per Ft. per Hour.	AIR, CUBIC FT.		UNITS OF HEAT.		
				Steam.	Entering Air.	Exit Air.	Enter. and Exit Air = E − D.	Steam & Enter. Air = C − D.		Per Ft. per Hour = 52 × K ÷ F.	That would be warmed 100° by K. = K × 52 ÷ 100	Per Ft. per Hour = H × 1000 ÷ 16.	Pr. Dg. Diff. Temp. St'm & Air = K ÷ G	Estim. for 5 lbs. Steam & 32° Air, = L × 196.
		A	B	C	D	E	F	G	H	I	J	K	L	M
C. B. Richards, 1873-4,	Gold's Pin,		1	215	0	160	160	215	5.44	111	177	340	1.58	310
	Novelty,		1	"	"	156	156	"	5.09	102	159	318	1.48	289
	G. Whittier,		1	"	"	135	135	"	4.40	106	143	275	1.28	251
	Pipe Coil,		1	"	"	147	147	"	4.88	108	159	305	1.42	278
W. J. Baldwin, 1885,	Gold's Pin,	60	10	239	71	168	97	168	3.83	128	124	239	1.42	278
	Comp. Coil,	60	10	"	"	170	98	167	3.84	126	125	240	1.43	280
W. Warner, 1880,	Gold's Pin,	70	3	222	42	145	103	180	4.60	145	150	288	1.60	314
J. H. Mills, 1879,	Walworth,	40	5	227	33	142	109	194	5.00	149	163	313	1.61	316
	Mills,	60	5	"	78	162	84	139	4.08	158	133	255	1.71	335
		100 Cubic Ft. of Air per Ft. per Hour. Av.								**126**	**148**	**286**	**1.50**	**295**
Dr. Gray, 1875,	Gold's Pin,	90	20	259	33	125	92	226	6.54	231	213	409	1.81	355
J. R. Reed, 1875,	Whittier,	68	3	222	45	129	84	177	5.09	197	165	318	1.80	353
C. B. Richards, 1873-4,	Gold's Pin,		1	215	0	139	139	215	9.15	214	297	572	2.66	521
	Novelty,		1	"	"	132	132	"	8.70	214	283	544	2.53	496
	G. Whittier,		1	"	"	102	102	"	6.66	212	216	416	1.94	380
	Pipe Coil,		1	"	"	106	106	"	6.98	214	227	436	2.03	398
		200 Cubic Ft. of Air per Ft. per Hour. Av.								**214**	**234**	**449**	**2.13**	**417**
J. R. Reed, 1875,	Whittier,	68	3	222	52	110	58	170	5.50	308	179	344	2.02	396
	G. Whittier,	68	3	"	"	114	62	"	5.86	307	190	366	2.15	421
	Gold's Pin,	58	3	"	"	127	75	"	7.92	343	257	495	2.91	570
C. B. Richards, 1873-4,	Gold's Pin,		1	215	0	129	129	215	12.65	319	411	791	3.68	721
	Novelty,		1	"	"	121	121	"	11.90	320	387	744	3.46	678
	G. Whittier,		1	"	"	87	87	"	8.53	319	277	533	2.48	486
	Pipe Coil,		1	"	"	89	89	"	8.64	323	281	540	2.51	492
J. H. Mills, 1876,	Gold's Pin,	76½	10	239	81	159	78	158	8.49	354	276	531	3.36	659
W. J. Baldwin, Nov., 1885,	Gold's Pin,	60	5	227	82	150	68	145	8.16	390	265	510	3.52	690
	Comp. Coil,	60	5	"	"	152	70	"	8.16	379	265	510	3.52	690
		300 Cubic Ft. of Air per Ft. per Hour. Av.								**336**	**279**	**536**	**2.96**	**580**
J. H. Mills, 1876,	Gold's Pin,	76½	10	239	91	158	67	148	8.91	433	290	557	3.76	737
W. J. Baldwin, 1885,	Gold's Pin,	60	5	227	70	137	67	158	8.93	433	290	558	3.55	696
	Comp. Coil,	60	5	"	"	135	65	"	8.40	420	273	525	3.34	655
C. B. Richards, 1873-4,	Gold's Pin,		1	215	0	121	121	215	15.92	428	517	995	4.63	907
	Novelty,		1	"	"	113	113	"	14.86	428	483	929	4.32	847
	G. Whittier,		1	"	"	77	77	"	10.14	428	330	634	2.95	578
	Pipe Coil,		1	"	"	76	76	"	10.02	428	326	626	2.91	570
		400 Cubic Ft. of Air per Ft. per Hour. Av.								**428**	**358**	**689**	**3.64**	**713**
J. H. Mills, 1876,	Gold's Pin,	77	6	230	88	158	70	142	10.04	467	327	628	4.42	866
	Walworth,	67½	6	"	"	142	54	"	8.88	534	289	555	3.91	766
		500 Cubic Ft. of Air per Ft. per Hour. Av.								**501**	**308**	**592**	**4.17**	**816**
J. H. Mills, 1876,	Walworth,	85	20	259	90	160	70	169	13.69	636	445	856	5.06	992
	Gold's Pin,	76½	20	"	"	166	76	"	15.16	649	493	948	5.61	1100
		600 Cubic Ft. of Air per Ft. per Hour. Av.								**643**	**469**	**902**	**5.34**	**1046**
J. H. Mills, 1876,	Walworth,	85	3	222	90	142	52	132	11.61	726	378	726	5.50	1078
	Gold's Pin,	76½	3	"	"	145	55	"	12.54	741	408	784	5.94	1164
		[illegible] er Hour. Av.								**734**	**393**	**755**	**5.72**	**1121**
J. H. Mills, 1876,	Gol [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	13.43	855	436	839	6.31	1237
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	15.30	888	497	956	6.21	1217
		[illegible] v.								**872**	**467**	**898**	**6.26**	**1227**

EXPLANATION OF DIAGRAM No. 19.

Diagram 19 shows the heat from indirect radiators with different amounts of air supplied. The line data is from table No. 12.

Line A shows the amount of heat per square foot of heating surface if the temperature of the air is raised 100°, the initial density of the air being that due to a temperature of 32° Fahr.

Lines B and C are plotted from experiments with two radiators, representatives of wrought and cast iron construction; B, the standard Gold's pin, and C, the wrought-iron box coil. The small circles refer to the results of actual tests, the number attached to each being for reference to the same test in table No. 12.

The curved *dotted* lines show the heat transmitted by air in contact with metal surfaces according to theory of Rankine and Professors Thurston and Trowbridge, the lines selected being the nearest to those by experiment shown.

In the lower diagram, No. 20, line D, we see that practically the same increased efficiency of heating surfaces may be obtained by raising the temperature as by increasing the quantity of the air passed.

The heat in this line D is obtained from a constant supply of air (644 cubic feet) and varying steam temperatures due to the different pressures employed of from 1 to 20 pounds. The circles on the lines are for experiments with the Walworth wrought-pipe radiator.

Line E also passes through the same increase of temperature, but the air is limited to that obtained from a ten-foot flue, and thus fills in the scale from 420 to 780 heat units, or about where the line of larger air supply begins.

Line F shows the general and common condition and results obtained from indirect heaters with steam or water circulation and gravity pressures found in the average conditions of indirect heating and delivery on the first floors of dwellings; and we see that by doubling the pressures, from 2½ to 5 pounds, and from 5 to 10, and from 10 to 20 pounds, we get a corresponding increase of heat of about 20 per cent for each time we double the pressures.

In the last section of diagram 20, lines G and H, the results with steam and water circulations (gravity conditions) are compared, all the experiments being made with the same heaters; the steam experiments, however, not being carried above 10 pounds pressure, while the water line is run out to its legitimate results at a temperature of 300° seen in other tables; and we may thus note the greater flexibility of the water line, beginning to give off heat at a temperature 100° lower than the other, but at the same temperature would only be in the middle of its possible and practical efficiency. See also tables 10, 12, and 13.

DIAGRAM No. 19.

GRAPHICAL REPRESENTATION OF THE HEAT FROM RADIATORS. *(Indirect.)*

Conditions: Increased Air; Steam Pressure Constant at 5 lbs.; Temp., Air 32.
Line A. Air raised 100° from 32° Fahr.
Line B, Gold's Pin Radiator, by Experiment, Table No. 12.
Line C, Wrought Iron Pipe Coil, Staggered Tubes (Richards' Table No. 12).
Dotted Lines by Theory of Conduction and Radiation of Heat.

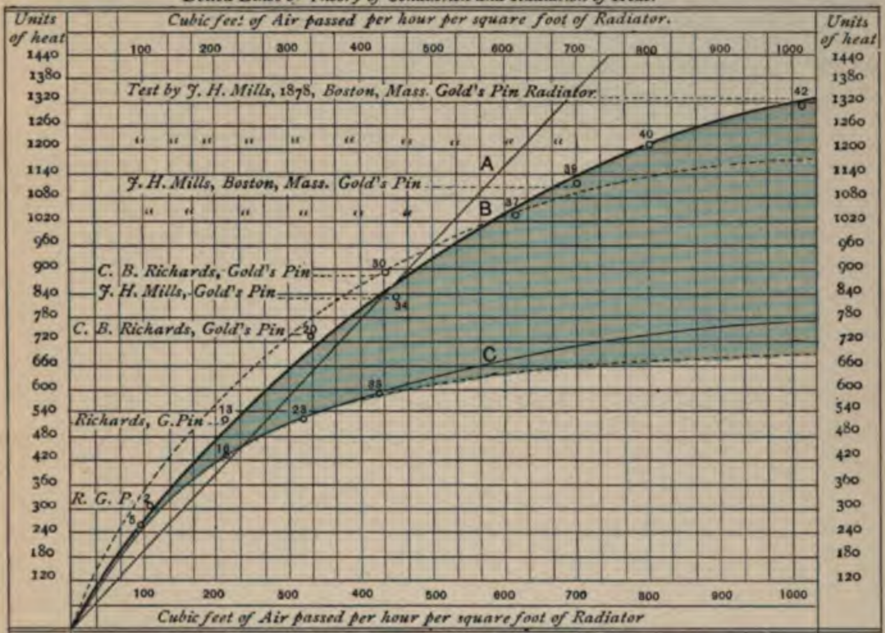
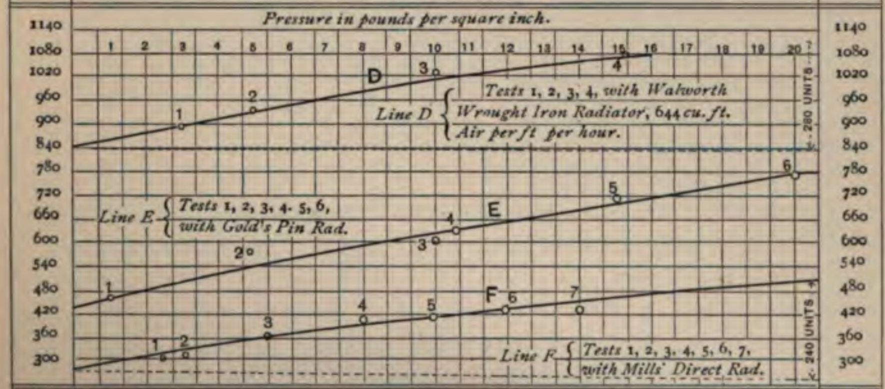
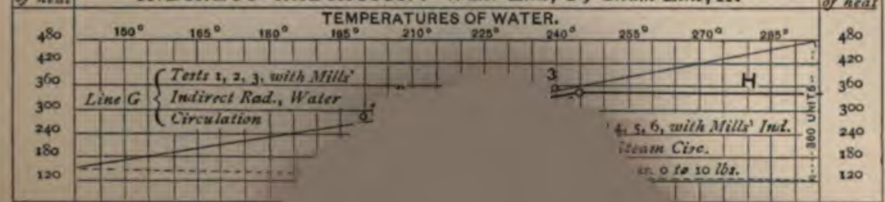


DIAGRAM No. 20 Lines D. E. and F.

Line D, Increased Pressure Steam; Air Constant by Blower; Temp. Air 32°
" E, " " , " " Increased. 10 ft. Flue: " " "
" F, Direct Radiation; Pressure Steam as below; " " 70°



INDIRECT RADIATION: Water Line, G; Steam Line, H.



In the following table, No. 13, may be seen the continuation of experiments under *gravity conditions and low temperature steam and water circulations*, also in the last experiments the increased effect obtained with a ten-foot flue, and finally the results of using a blower on the same surfaces. We may also note that the temperature of the water of condensation, column D, is scarcely affected by doubling and trebling the quantity of the air passed.

Steam and water within the radiator at equal temperatures have nearly the same efficiency in warming air. Owing to the great specific heat of water and its density, the amount of heat contained within the radiator is much greater for water than for steam; but the latter flows more rapidly, and its condensation on the surface of the metal liberates latent heat, which becomes sensible in the iron, and maintains it at nearly the same constant temperature.

The standard for measuring the efficiency of indirect water coils and heaters is substantially that employed for steam: viz., the amount of heat that would be imparted to the air in a given time by a square foot of the surface.

The conditions are fully set forth in table No. 13, being the results of numerous experiments by W. J. Baldwin and the writer. They are as seen on eight different kinds of heaters, and embrace all the various conditions met with in this class of warming. We may call attention to the fact that in the final summing up, column M, we note the units of heat for similar and standard conditions: steam, 339; water, 359. The deductions to be drawn may be summarized as follows: —

1st. That there is a general agreement among engineers and experimenters as to the duty and value of any heating surface when placed *practically under the same conditions of heat and air.*

2d That as air is the only medium of conveyance from indirect heaters to the rooms to be warmed, the supply and delivery of the air is practically the whole question, as far as the value of these heaters is concerned, and that in effect it is not how much of any kind of heating material is employed, but is it so arranged and combined as to yield its highest possible duty?

For the first-floor delivery (gravity conditions) impeded by gratings and registers, we may not expect results higher than shown by our first nine experiments,* and with one hundred cubic feet of air passing per square foot of surface per hour, 295 units.

The next two groups, experiments 10 to 25, may be taken to represent the work done on the second floor or under a ten-foot flue, [illegible] units; the last five results being the heat that could be obt [illegible] air in the stated quantity were supplied to the radiators by mechanical means. Average, 984 units per foot.

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* See table No. 12, page 367.

TABLE No. 13.

Comparisons of ***Water*** and ***Steam*** Circulation, with Indirect Radiators, ***Natural*** and ***Forced*** Air-supply.

No. for Reference.	RADIATORS BOXED IN STACKS, OPEN BELOW, AND WITH OUTLET ABOVE FOR HEATED AIR. THE DUTY OF RADIATOR BEING DETERMINED BY THE **VOLUME AND TEMPERATURES OF THE HEATED AIR.**	Square Feet of Surface.	Square Inches of Air-Outlet.	TEMPERATURES.				Difference of Temperature.		Cubic Feet of Air.		Units of Heat Per Square Ft. per Hour.		
				Water or Steam.		Air to be Warmed.								
				Flow.	Return.	Cold.	Warm.	Steam or Water and Cold Air.	Warm and Cold Air F – E.	Velocity of Hot Air Feet per Minute.	Per Sq. Ft. per Hour at Uniform Density $\frac{204 \times B \times I}{A \times (459+F)}$.	Recovered J×H÷52.	Per Degree Diff. Steam or Water and Air. K÷G.	Reduced for Air 32°. Water or Steam 228° = L×196.
		A	B	C	D	E	F	G	H	I	J	K	L	M
	ENGINEERS, RADIATORS, AND DATES.			RADIATORS WITH WATER CIRCULATION.										
1	W. J. Baldwin { Box Coil . . . . Nat. Draft Water	74	192	192	176	85	134	99	49	119	106	99	1.00	196
2	1886 { Compound Coil . . . . " "	48	192	195	185	85	143	105	58	87	117	131	1.25	245
3	J. H. Mills { Albany Cast . . . . " " "	60	78½	202	172	38	128	149	90	271	123	213	1.43	280
4	1885 { Box Coil . . . . " "	55	82	205	162	45	135	138	90	283	145	251	1.82	357
5	W. J. Baldwin { Box Coil . . . . " " "	74	144	206	186	78	150	118	72	229	149	206	1.75	343
6	1886 { Compound Coil . . . . " "	48	144	206	194	78	166	122	88	151	148	250	2.05	402
7	J. H. Mills { Gold's Pin . . . . " " "	100	144	214	178	28	143	168	115	300	146	323	1.92	376
8	1885 { Mills' Indirect . . . . " "	100	144	214	181	28	138	169	110	320	157	332	1.96	384
9	Staggered Tube Coil Radiator, Shakelton's " " "	55	50	198	159	34	116	144	82	470	158	249	1.73	[illegible]
10	J. H. Mills { Mills' Indirect . . . . . . " " "	100	144	196	155	40	111	135	71	396	204	279	2.07	[illegible]
11	1885 { Gold's Pin . . . . " " "	100	144	196	155	40	114	135	74	412	211	300	2.22	[illegible]
	AVERAGES	. . . .	. . . .	**202**	**173**	**53**	**134**	**135**	**82**	**276**	**151**	**239**	**1.75**	[illegible]
				COMPARISON OF STEAM AND WATER UNDER SIMILAR CONDITIONS AND TEMPERA										
12	J. H. Mills, 1884 . . } Box Coil . . . Nat. Draft } Water	55	50	210	163	50	146	137	96	348	107	198	[illegible]	[illegible]
13	C. B. Richards, 1874 } Steam			215		0	147	215	147		106	305	[illegible]	[illegible]
14	J. H. Mills, 1884 } Mills' Indirect . . . " " } Water	100	144	220	180	28	136	172	108	296	146	303	[illegible]	[illegible]
15	" " 1879 } Steam	60		227		78	162	149	84		151	255	1.71	[illegible]
16	W. J. Baldwin { Compound Coil . . . " " } Water	48	144	206	194	78	166	122	88	151	148	250	[illegible]	[illegible]
17	" " } Steam	60	144	220		62	170	158	108		146	303	[illegible]	[illegible]
18	J. H. Mills, 1884 . } Gold's Pin . . . . . " " } Water	100	144	240	200	26	154	194	128	341	163	401	2.07	[illegible]
19	W. J. Baldwin, 1885 } Steam	60	144	220		62	157	158	95		161	295	1.87	[illegible]
	AVERAGES . . { Water	. . . .	. . . .	**219**	**184**	**46**	**151**	**156**	**105**	. . . .	**141**	**288**	[illegible]	[illegible]
	{ Steam	. . . .	. . . .	**221**		**51**	**159**	**170**	**109**	. . . .	**141**	**289**	[illegible]	[illegible]
20	J. H. Mills. Walworth. 10-foot Flue . } Indirect Radiators { Steam	66	217	231	192	84	138	147	54	410	461	479	3.26	[illegible]
21	" Forced Draft "	66	217	228	180	94	135	134	41	1,210	1,366	1,077	8.04	[illegible]
22	June 16, 1876. Gold's Pin. 10-foot Flue "	76	217	231	184	84	155	147	71	380	360	492	3.35	[illegible]
23	" " Forced Draft "	76	217	228	150	94	145	134	51	1,185	1,143	1,121	8.36	[illegible]
24	Nason. " 10-foot Flue . "	85	217	228	178	83	133	145	50	605	534	513	3.54	694

NOTE.—For No. 5, 15, 17, and 19 the heat recovered is that due to the amount of steam condensed (see Table 12).

Table No. 13, page 371, gives the result of experiments with indirect radiators where water is the heating medium. The examples in this table include experiments made by Mr. Wm. J. Baldwin and the author, the indirect radiators tested being the Mills (interlocking surface),* the Gold's Pin (cast iron with extended surface), and the compound coil (extended surface, wrought iron), and the ordinary pipe coil, and Albany radiators (cast iron).

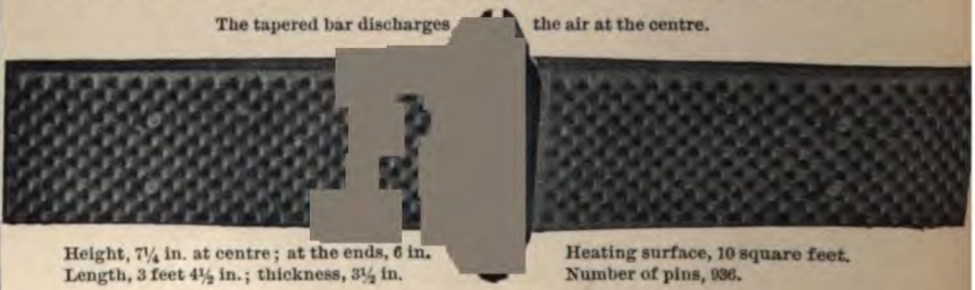
These experiments showed that the temperature of the air (as would naturally be expected) was the same for water and steam at *similar temperatures*, the surface showing a nearly equal efficiency.

The duty of indirect water surface here ranged from 100 to 400 units, the air being increased from 100 to 200 cubic feet per foot of surface per hour. These amounts of air were drawn through the radiator by the suction of a flue ten feet in height.

It should be observed that indirect surface may be supplied with water at a lower temperature than direct, since, by increasing the amount of surface in the stack, the temperature of the air delivered to the rooms can be maintained.

FIGURE No. 20.—IMPROVED GOLD'S WATER PIN RADIATOR.

The tapered bar discharges the air at the centre.



Height, 7¼ in. at centre; at the ends, 6 in.
Length, 3 feet 4½ in.; thickness, 3½ in.

Heating surface, 10 square feet.
Number of pins, 936.

The power that would be obtained by the more rapid cooling, by decreasing the sizes of the pipes and compartments that expose the water to the cooling effect of the air and radiation, may be secured in cast-iron radiators by extended surfaces, without incurring the disadvantages of decreasing the channel for the flow of the water. By means of solid projections in the form of pins, gills, etc., the cooling of the water may be more than doubled, or even tripled.

As the inside surface remains smooth against which the water circulates, and allows an ample and unobstructed channel, there is no increase in the frictional resistance, which is sometimes fatal to the employment of small pipes for a like purpose.

Radiators of this construction are illustrated in plate 35, and an example of the same principle applied to wrought-iron surfaces, in the form of a spiral coil wound around the outside of the pipe, is shown in plate No. 37.

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* See page 364.

CHAPTER XXI.

THE DISTRIBUTION OF HEAT.

PART V.

HOT AIR AND STEAM FURNACES.

HAVING fully considered the generation of heat, its absorption by boilers and furnaces, and its progress into and through various heaters and radiators, we have now to examine the mediums of distribution, which must also include the systems by which the heat is conveyed to the radiators, and from them to the rooms and spaces to be warmed.

From the writer's special devotion to other systems than hot air, it should not be expected that he has had any individual experiences and certainly no preferences for this more than common method of misapplying heat.

Yet, to write or treat of heat in its special use and application to buildings, and not notice the most common and oldest application of it to domestic and commercial uses, would indicate either a want of knowledge or a lack of fairness towards a prominent system and those who have labored to advance and perfect methods which, so to speak, have been the stepping-stones for those who either write or work to-day.

While there is much in a hot-air furnace and the usual method of securing and circulating the air that is both doubtful and dangerous, it does not follow that there can be nothing either safe or desirable in such a system; and the special hue and cry of nearly all parties connected with and operating other systems seems open to counter-charges of ignorance of fact and a willingness to distort truths in the interest of their particular trade and vocation.

The author's position in this matter is easily defined, being a "free lance;" unencumbered by rival interests of manufacture or sale, he can look up and down the lines of those who strive for power and place, desirous mainly to advance the worthy [illegible] both furnace, steam, and water-heating systems are [illegible] each other and to all those who have labored, as [illegible]ard to immediate return.

That there could be a good and reliable warm-air furnace system, there should be no question. That there are more defects possible with a hot-air furnace than with steam or water methods, need not be denied; yet, in view of the many actual and probable failures with all other methods, it seems well to go slow, when condemning any system, because certain individuals make failures in applying it. Such criticisms as the author offers are in this, as in other cases, advanced only in the interest of all his readers, be they manufacturers or consumers. So with any words of commendation; they are recorded because there is no system without its good points, or without true and faithful workers in the lines that they, as well as their competitors, believe to be sound and remunerative.

The earliest writers on the construction of stoves were Kesler, of Frankfort, in 1614, Savot in 1625, Glauber in 1669, and Delesme in 1686. In 1713 M. Gauger published a treatise on the construction of fire-places; it contained a most lucid explanation of the methods of economizing fuel, based on the soundest principles of philosophy. It was the first attempt to apply the known laws of heat to the construction of fire-places.

The translator, Dr. Desguliers (1715), added a chapter on stoves, and the work in that new form was a complete epitome of all those principles that Franklin and, after him, Count Rumford so successfully brought to the public notice, and which, if strictly carried out, would form, even at the present day, the best guide to the proper construction of stoves and fire-places.

In 1796, Count Rumford published his essays on the "Management of Fire" and the "Economy of Fuel." The error shown by M. Gauger to exist in the construction of fire-places still existed, and Count Rumford stated that, in order to obtain the greatest effect from the fuel, the sides of the fire-place ought to be at an angle of 135° with the back of the grate. The reduction in the size of the throat of the chimney was an improvement which he effected.

Dr. Franklin, in 1744, invented a stove for burning wood, in which he introduced the principle of heating the air, much in the manner first recommended by M. Gauger, by means of a double or hollow back. This stove was in the form of an oblong box with the front removed. The smoke escaped over the top of this flat chamber, and passed *downwards* between it and the real back of the stove, and then into the chimney. (Franklin's Works, Vol. II., page 225.)

This hollow chamber communicated underneath the stove with a tube opening into the external atmosphere, and a quantity of air thus passed through the flat chamber and into the room through small holes left in the sides.

Here appears to be an early and perhaps the first attempt to construct economical stoves or furnaces combined with the principle of sanitary heating and air supply to enclosed rooms.

On the general subject of furnace or hot-air heating, the writer is not supposed to be equally versed as with the details of a steam or water apparatus. But where the difficulties of successful application and the many failures of the system are common property, the writer may be excused his references. He does not seek to parade these unduly because his own efforts have been in another and more favorable direction.

He would even prefer to say a good word for the points of value which a warm-air system might possess in the hands of educated, skillful, and honest men.

Certainly the hot-air or furnace system is the first on which we emerged from the barbarous condition of close stoves and no pure air supply to whatever of value we can now show; and it was to a furnace man and writer that we owe the first, and I had almost said the best, exposition of the principles of rational and sanitary heating extant.

Ruttan System. Doubtless most of my readers have heard of the "Ruttan system of warming," and perhaps have not heard any good of it, unless they have come in contact with its late and changed construction, or, rather, what has been worked out of the principles which Mr. Ruttan advocated and his experiments to prove them. Standing in relation to this, as to any furnace system of warming, with nothing to gain, and being, so to speak, on the other side of a competitive line between steam and furnace goods, the writer is yet moved to say a few words about this early inventor and of those gentlemen who, having faith in the principles laid down by Ruttan, have carried his banner through battles innumerable and on to victories, over which both they and the whole heating fraternity *ought to feel proud.*

It has been the custom to extol with pride the discoveries of Watt, of Fulton, and of others, whose inventions did not carry *them* further in the several sciences than did those of Ruttan, and whose devices have been so improved upon as to leave them unrecognizable to-day. Why, then, in another although humbler line should any strive to ignore the labors and belittle the efforts of those who have first put their word on record, and have, after years of labor and the expenditure of thousands of dollars, made the warming and ventilation of buildings by a furnace method a signal and lasting success?

Writers and others supposed to be versed in methods for warming and ventilating buildings have found it convenient to sneer at or "be amazed" at some of the expressions of Mr. [illegible]. found self-satisfaction," when giving his [illegible] to the world. They also quote glibly i [illegible] early applications of the principles and theories advocated by him. It may be stated that, when Mr. Ruttan wrote, in 1862, there were no books in print in this country that could compare with his treatise, illustrated, as it was, with fifty-four colored plates and diagrams.

1843, when Mr. Ruttan first began his experiments, was a date when ideas relating to warming and ventilation may have been, as they doubtless were, in a crude state. Certainly but few of the men now engaged in the manufacture or application of heating apparatus can compare notes, while even those who have theories to-day to expound may profitably consider that, forty years before they put pen to the paper or hand to the wheel, Ruttan had laid down *principles* and *precedents*, which must be incorporated in any practical and successful heating apparatus, be it of the furnace, steam, or water variety. Of course, contemporary and later furnace men found comparisons between what they had to offer and the Ruttan goods and methods odious; and men who have all their lives been trying to "put the camel through the eye of the needle" have no patience with those who reverse this old-time practice, put the needles on the camel's back, mount with them, and ride to a successful market.

Neither can any commendation be expected from men who make or sell steam or water-heating apparatus. The furnace man and all his methods are to them alike a delusion and a snare.

Dr. John S. Billings, however, writing in 1884, while dissenting from some of Mr. Ruttan's theories and manner of expressing them, was yet moved to say: —

"Although I cannot admit Mr. Ruttan's claim to have discovered the only perfect system of heating and ventilation, there is, nevertheless, much in his book that is true and suggestive to the architect, more especially as regards private dwellings.

"Mr. Ruttan says truly: 'If you open your aperture at the top, and the air you bring in is warm, or if you open the aperture at the bottom, and the air you bring in is cold — in either case the body of air will not budge; your warm air will go through the body, straight to and out of the top aperture; and the cold air will do the same through the bottom aperture. The consequence of this state of things is easily seen — *you will neither warm, cool, nor ventilate the room.*

"'*But if you want to ventilate your room to warm it*, and open the bottom aperture, *you will succeed in both;* and if you wish to ventilate your room to cool it, and open the top aperture, you will succeed in that; because in the first case the fresh air will be the warmest, and will not stop until it comes in contact with the ceiling, where, spreading out in level strata over the whole ceiling, it will keep its relative position to the whole body until it reaches the bottom and passes out through the aperture; and so of the cold air, if you open the top and let the air out through at that point. In both cases every particle of air should be removed from the room, because, as air of one temperature cannot, by any means, be made to move or stop out of its level, it follows that every *particle* of every *stratum* must, in its turn, leave the apartment.

"'If we want to ventilate our room to *cool it*, we must let the air out *at or near the top*, and supply its place with cool air, which, of course, will distribute itself over the floor of the apartment; and this has been the policy in nearly all of our former modes of ventilation; cold air is introduced, and while taking up the heat from the occupants of the room and the fire, immediately escapes through an aperture provided for the purpose near the ceiling. Thus proceeding on the erroneous notion that cold air only could be pure, they have actually been freezing the people when they wanted to warm them.

"'If, on the other hand, we wished to ventilate our house and *warm it, we must take the air out at or near the bottom*, thus keeping up a continual exhaustion of the heated air; and if we wish to set the body of air in the room in motion, upward or downward, we must, of course, bring in the necessary amount of outside air to do it. If we want to warm the room, the air we bring in must be warm, and if to cool it, it must be cool. It depends now entirely upon where you open the aperture to let the air out whether you set this body of air in motion or not.'"

This is the earliest and soundest dictum given by any writer on the warming and ventilation of buildings.

The most that has been accomplished in the way of heating by means of hot air, where ventilation at the same time has *not been ignored, has been done by the so-called Ruttan system.* The system combines the patented inventions of Henry Ruttan, of Canada; I. D. Smead, of Toledo; and B. R. Hawley, of Ohio.

For heating, the tubular furnace is used, which, on account of the large surface that is thus brought in direct contact with the fire, is economical as a consumer, and the large surface which is also subjected to the air, makes it effective as a heater.

The fire box, by its construction, presents a large surface to the fire and the air. The surface is further increased by requiring the smoke and burned products to pass successively through the tubes. The furnace is set in masonry, into which the cold air is admitted for warming, and passes out at the tubes into the r [illegible] method of admitting the heated air into the room is emb [illegible] of Mr. Smead, patented by him in 1882.*

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* For cuts of this furnace an [illegible]

In the Ruttan system the foul air is drawn out of the room from the bottom, through registers near the floor. These outlets are placed, when convenient, on the sides of the room opposite the final outlet; so that foul warm air, as it leaves the room, will pass under the floor, which it is thus intended to warm. The foul air, thus passing from the adjacent rooms, is all collected into a foul-air room adjacent to the smoke chimney, into the bottom of which it communicates by a large opening. The theory and practice of the system may be summarized as follows:—

The air, warmed by the furnace, rises through the air flue into the room, where, within convenient reach, a hand-knob is placed for the regulation of hot and cold air. The warm air, after its admission, rises to the top of the room, which, on being filled from the top downward, presses the cold air down and out through the outlets. The foul and cold air, being at the bottom, is thus drawn off, and the upper part of the room kept constantly filled with pure warm air. The floor is warmed by the warm air as it passes on its way out. This last air is kept in motion by the draught of the chimney into which the foul-room opens.

It may be said in favor of this system that it shows throughout a studied effort toward conformity with natural laws, and is therefore a valuable contribution toward the solution of the difficult and all-important problem of ventilation. It is a practical system, and doing comparatively good service.

It appears that the first gentlemen to take up Mr. Ruttan's plans were Mr. Hawley, W. A. Pennell, and Mr. L. Grover, of Normal, Ill. This was in 1866. The firm purchased from Mr. Ruttan such patents as he had, a few patterns, and the right to use his name, their idea being to furnish plans and specifications and collect a royalty on the same. It was not their intention to manufacture a heating apparatus of any kind, except, perhaps, the ventilating stoves. Herein lies the key to whatever of failure or disaster that followed, to be repeated by several following firms before a practical and efficient heating apparatus was evolved from the ashes of these several burned-out fires.

Had the first or second companies realized that however good a theory in the line of mechanics (for heating and ventilating is but the working out of the higher mechanical and natural laws), that the machines, to fit their ideas and laws, must be ***invented*, *constructed*, *and carefully applied***, before the theory itself would have any chance to prove its value, or themselves reap any reward, their own theory and practice would have been differently shaped. But as neither of these gentlemen were mechanics or engineers,—two being retired merchants, the third, perhaps, like Mr. Ruttan, a sanguine inventor,—they did not grasp the mechanical and practical problems involved, and therefore failure was scored, not against their individual weakness, but, as usual, against the ideas and plans which they undertook to give a practical trial; and manufacturers of rival appliances were happy because the new system had failed to meet the guarantees of the somewhat unpractical owners.

It seemed that the point overlooked or not seen at all was that, if a large volume of air was to be warmed, there must be a large heating surface to warm it; and, as no furnace then on the market had ever been called upon to ventilate as well as to warm, there were absolutely no tools with which to do the required work.

This state of things compelled Pennell & Co., and later those who joined them, to invent, construct, and apply a furnace which in the end proved the key to the successful accomplishment of all their wants and desires.

Considerable work was done in the years 1870 and 1871.

In 1877, the amount of iron manufactured into heating apparatus was some two hundred thousand pounds, and in 1884 over three million.

In 1885, two more firms were organized bearing the name of the Ruttan-Smead Warming & Ventilating Company. This was done in deference to the engineering ability and experience of Mr. Smead, who, it was claimed, and justly, had more to do with the perfection of the system than even Mr. Ruttan, and because, as soon as success did crown the efforts of this indefatigable and tireless worker, other parties started up, claiming to put in the Ruttan or any other system of ventilation.

In these days of piracy and invasion of all rights, patented or otherwise, it is interesting to see "the vultures sit on the edge of a successful stream (they had not the courage or ability to swim), waiting for the tide to run low (the patents to expire), so that they can 'walk over dry shod.'"

It is noticeable that the first furnace attempted under the new ideas was of *wrought iron*, and in the light of that day doubtless promised great advantages. We are told that "many of them did not last a month," that they "seemed tired of life," "and would sit down with a terribly discouraged appearance." It is easily seen that the second failure was a terrible backset to the Ruttan system and a great loss to its owners, as well as a humiliation to its friends.

In this distress, they turned again to their first love, and proceeded to construct a furnace of *cast iron*, which under some modifications brought them through their trouble (in this direction), and star
to-day as the distinguishing feature of their final success.

Had the writer the time and space, he would follow
of this forlorn hope as they rose and fell with the

enterprise, worthy, shall we say, of a better cause? No, for there was no better cause for time, talent, and money than to expend itself in the effort to develop and perfect a practical and efficient system of warming and ventilation.

Whatever may have been the defects of Ruttan's earlier and limited applications, for he was an old man when he began to write and experiment, his efforts were in the right direction, and should place his name with that of Rumford and Franklin, and with that other philosopher whose only plea was, that "he loved his fellow-men."

Neither have I any idea that Mr. Ruttan in his book intended to disparage the writings of Reid and Wyman, but that simply he thought that their ideas did not go far enough to comprise in any sure and efficient way "*a complete and continuous change of the air in all inhabited structures.*"

While having no personal acquaintance with either the individuals or companies comprising the present Ruttan-Smead firm, the writer is indebted to Mr. Isaac D. Smead for the handsome and instructive diagrams of the movement of air in rooms under heat and the colored diagram of Smead's system of continuous ventilation, also the two plates of the Ruttan tubular air warmer, and smaller portable furnace, with its simple and efficient arrangements for a pure air supply.*

While there are other and more modern furnace goods, these, once seen, will leave a favorable impression on any practical and unbiased reader. See last pages for cuts of these furnaces.

While intending, as stated, no special advertisement of any one apparatus, it seems only fair, both to our readers and to the parties who have so long labored in a good cause, to state what they claim to have accomplished and what seems proven by the testimony of school boards and superintendents.

The following statistics of the comparative cost of warming school buildings by the Ruttan-Smead, by steam, and by the old hot-blast furnace arrangements are in themselves suggestive.

They are taken from the circular of Isaac D. Smead & Co., Toledo. The letter from Superintendent H. M. Parker speaks for itself, and also to the point of the other statement in the same line of work. As the parties to this circular and method of heating say nothing of a fourth system, we may conclude that no cases of warming by a water circulation and apparatus had then come under their observation. The writer will, however, attempt to supply these figures later in connection with the cost of steam and water heating in different cities.

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* We should have been glad to have set here the fine cuts illustrating the movements of air in rooms; but, being in stone, they could not be reduced to the required size. See Appendix.

In admitting the statement of the comparative cost said to have been found by extensive and practical experiments, it is due to the writer's position, as a steam and water furnace engineer, to say that he cannot personally vouch for the peculiar and remarkable gain in economy shown by the Ruttan-Smead over the other systems.

A difficulty presents itself in making practical analysis of the figures presented, in that no collateral data are given; we are not told how much space is warmed in each case, what are the class and exposure of buildings in which the heating was done, or what were the proportions of wall and glass in the buildings, and other influencing data.

Then, although this was in the year 1884–1885, the furnace and steam apparatus noted may and likely were of a much earlier date and possibly of an inferior pattern and construction, and even under different management; so that finally there are many items of importance lacking, that would have an important bearing on any results obtained.

No one knows better than the writer that a great proportion of the earlier and much of the present steam-heating apparatus is far from perfect; some of it is constructed of poor material in the way of boilers and radiators, arranged and proportioned in such a way as to forever preclude either efficient or economical results.

We have seen all through the first part of this treatise how important a part the science of combustion plays in all apparatus for the generation of heat; and yet, as this is a science in *chemistry* instead of mechanics, the average foundry, furnace, and boiler man has not had any conception or control of it. If now a set of intelligent, educated men, bent on finding this last and omitted key to all furnace construction, combine on any one of the three systems mentioned, superior and even remarkable results may be expected.

That a poorly proportioned and constructed steam apparatus, having contracted grate and absorbing surfaces, with small lines of connections, should yield none of the desirable results, and be 20, 30, or even 50 per cent short of a desired and practical standard, is only what may be expected. *The silk purse is not yet made from the sow's ear.*

Given such an apparatus,—and their name is legion,—connect this to coils and radiators located in the rooms and without a pure-air supply for purposes of ventilation, and there would be little to choose between steam and almost any fairly arranged warm-air furnace plant.

That the Ruttan goods and system are superior, might be fairly predicted when we see that they employ more than *double the grate and absorbing surfaces*, and do not lose sight of the *combustion* at the start, or of the sci [illegible] *ilation afterwards*. In any furnace system of heating [illegible] ole medium, it must have preferences, and will th [illegible] r practical details.

*COST OF WARMING SCHOOL BUILDINGS.

IN TOLEDO SCHOOLS.

For winter of 1884-85:—

With Ruttan-Smead apparatus	$22.79 per school-room.
With steam-heating apparatus	52.68 " " "
With hot-air furnace	86.25 " " "

IN DETROIT.

With Ruttan-Smead apparatus (frame building) .	$25.25 per school-room.
With steam-heating apparatus (brick building) .	54.00 " " "

IN WASHINGTON, D. C.

With Ruttan-Smead apparatus	$24.20 per school-room.
With steam-heating apparatus	56.00 " " "

ELMIRA, N. Y.

With Ruttan-Smead	$15.50 per school-room.
With steam	40.70 " " "
With hot-air furnace	37.50 " " "

There are ninety-nine school-rooms in Toledo warmed by the Ruttan-Smead apparatus, and nearly as many in Washington.— *Toledo Blade*, May 18.

There are now one hundred and twenty-seven school-rooms in Toledo warmed by our apparatus — October 1.—*Isaac D. Smead & Co.*

ELYRIA, O., May 14, 1884.

TO WHOM IT MAY CONCERN :—

We have had in use since the 10th of September, 1883, two No. 8, and one No. 7, Ruttan-Smead furnaces. These furnaces have been used to heat and ventilate a school building. The following statements will show how well the work is done:—

1st. They have warmed 121,960 cubic feet of school-room, besides frequently allowing heat to escape into the halls. This is equal to ten rooms of 12,196 cubic feet per room, and that is larger than the average school-room.

2d. They have ventilated these rooms better than I have ever known school-rooms to be ventilated in an experience of a quarter of a century in my profession.

3d. They have ventilated equally well the water-closets in the basement of the building.

4th. For two weeks during cold weather, six observations of the temperature of the high school room, which is 48 x 30 x 16, were made daily, from 8.30 A. M. to 3 P. M. At every one of the sixty observations the temperature was 68° or 70°, F. The thermometer registering the above was about three feet from the floor. A thermometer was placed upon the floor, and remained there all day. Six observations were made, and it was 68° each time.

When the mercury was 10° below zero on Monday morning, there having been no fire in the building since the preceding Friday, the fires in the furnaces were built at 6.30; and 8.30 the temperature in all the rooms was 70°.

As our building was new, we started fires every day after entering it, the 10th of September, and we have had but few days this spring when we have not started a fire in the morning.

The three furnaces have consumed exactly 63 tons of soft lump coal. Ventilating stoves (?) heating the same amount of space, have consumed 70 tons of the same kind of coal, and have poorly ventilated the rooms. We have saved in fuel, gained in even temperature and in ventilation.

A recent examination into the condition of the furnaces showed them to be in a good state of preservation, and that they need no repairs.

I am convinced, from careful observation, that the Ruttan-Smead apparatus will do all that is claimed for it, if the directions are strictly followed, and that any careful man of average intelligence can learn to run the apparatus successfully.

Respectfully, **H. M. PARKER,**
Superintendent of Schools.

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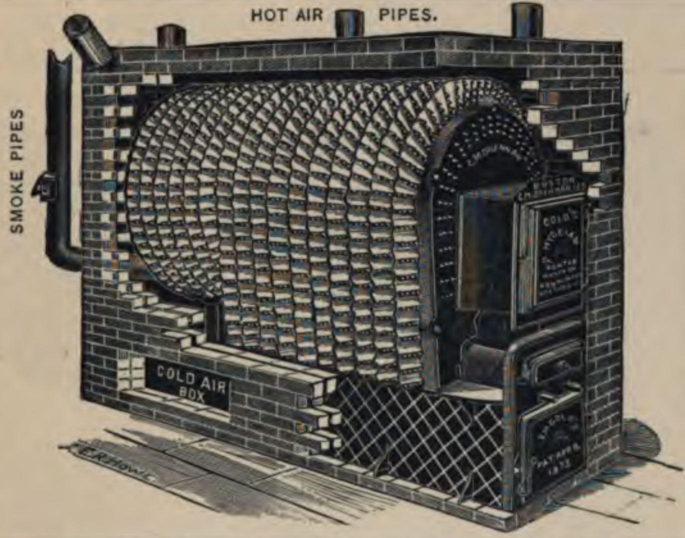
* Circular of Isaac D. Smead & Co., Toledo, O.

THE WARMING AND VENTILATION OF BUILDINGS.

Of the three principal methods of circulating and distributing heat,—by *air*, by *steam*, and by *water*,—that of heating the air in furnaces and sending it direct to the rooms to be warmed, while being the most universal, is at the same time the most limited in its operation, and I might say the most unsatisfactory. Not that this need be so, yet there are many difficulties in the way of a satisfactory and permanently successful hot-air apparatus. 1st. Because of the way the air is warmed, it being brought in contact with a plate of iron on one side, which has a fire and direct heat on the other. Air being one of the worst possible non-conductors, it but poorly protects the furnace plates from overheating and cracking.

FIGURE 21.



• HYGEIAN HEATER SET IN BRICK-WORK

BRICK-WORK BROKEN OPEN TO SHOW THE EXTENDED SURFACES.

2d. The form of the average furnace is not favorable for the air to reach or be brought in contact with every part of the heated iron; and, as the air is but little warmed by conduction, and none by radiation in the furnace itself, it follows that the real work is done by but a small portion of the surface provided and estimated as available.

The difficulty of getting air in contact with hot surfaces has always been met with in all classes of "heaters," whether in a furnace, steam or water apparatus, and has led to distinct devices being employed to bring about the necessary *contact* of the air.

We may mention the corrugated and pin surface of the *Hygeian heater*, where the outside is many times that of the interior or fire surface—a simple yet efficient means of *reducing* the *temperature* of the ate while *increasing the air-warming surfaces;* securing, in fact, what l in name, a sanitary and safe air-heating apparatus.

Drennan & Co., 203 Tremont Street, Boston.

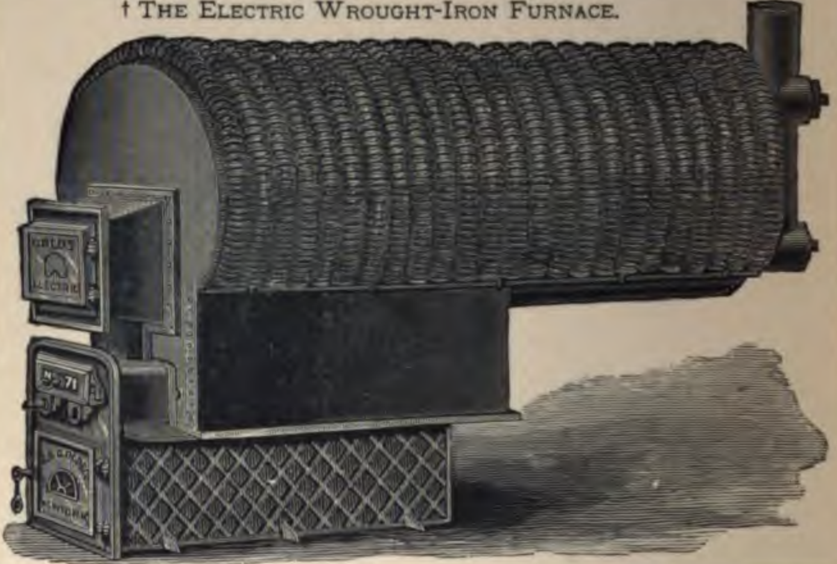
This principle, first incorporated in the celebrated *Gold's pin radiator*, is the one that gave it a "length of days," and a value beyond that of any other single piece of steam-heating apparatus.

A cut illustrating the *compound* radiator surface and its application to the pipe was given on page 359, also on page 361, showing the difficulty of heating air by plain pipe coil, and the increased height of the stack required over that with the compound coil and "pin" surfaces.

Later, a similar departure was taken by a son of the same inventor, and an extended surface was secured on a wrought-iron cylinder furnace, instead of a cast-iron surface, the results of which seem to be very similar to the former; although the extended surface in the latter case is itself first heated by *contact* and *radiation*, later imparting its borrowed heat to air by contact with itself.*

FIGURE 22.

† THE ELECTRIC WROUGHT-IRON FURNACE.



Returning to the general disabilities of the ordinary furnace, a very limited heating surface, limited grate, and generally restricted conditions are perhaps the mildest criticism that can be passed on a system full of special defects, not the least of which is the danger of passing the products of combustion through the joints into the heat chamber, and so into the living-rooms attached to it.

Nearly every furnace manufacturer and all the dealers will assure a customer that their particular construction is exempt from this common danger, but it is hardly possible that every one out of thousands of cast-iron furnaces is entirely exempt from this grave danger to health.

*** See cut and tables of experiments No. 13, p. 371. † Edward E. Gold & Co., Cliff St., N. Y.**

This also accounts for the rapid derangements of the furnace and the injury done to the air in contact with it; while, if the volume of cold air is reduced, as is often the case, to warm the room and save fuel, the temperature of the now less protected plate may, and often does, rise to 1,000° or 1,500°, and is then ready to set fire to everything which comes near either the iron or the air; to this state of things the numberless and distressing fires plainly attest, and also the many and rigid details of setting insisted on by the fire underwriters and boards of inspection. And still but little can be done, where the original plan of the furnaces is defective, and attempts a large amount of work with a small heating surface.

True, the owner and purchaser is often mainly to blame in confining a question of this magnitude to the ruinous effect of competition, since it is *morally certain that the lowest price will afford him the least amount of heating and grate surface, the smallest pipes and registers*,— conditions which, unhealthy and uncomfortable as he may, and generally *does*, find them, he can neither change nor improve short of total removal and reconstruction, generally at a price which would have given him a liberal apparatus to begin with, and saved him much discomfort,— and the trade, the blame which, justly or unjustly, attaches to failures of this kind.

There are many firms and individuals that will not lend themselves to a competition where a low price is the main condition of a contract, or where they can only hope to succeed by attempting to do that which is not practical to any honest and capable engineer.

It is safe to say that the great majority of hot-air furnaces are deficient in grate and heating surface. A furnace with 50 square feet of heating surface and 3 square feet of grate is more than an average size, while 1 with 100 and a corresponding grate surface is a white elephant in dimensions and construction.

On the other hand, a *boiler* for steam or water heating is *small*, with the largest amount of surface stated (see table No. 7), while the air-heating surfaces (radiators), to compass a given amount of warming, will be *six or seven times the furnace area*; the *boiler*, to absorb the heat of the fire, may be about 2 to 1 of the furnace cited. Sylvester found* that a square foot of his furnace would warm 1,574 cubic feet of air 60° per hour, yielding 1,800 units of heat per foot, when the temperature of the furnace plate was *five hundred and sixty degrees*; 700 feet per foot per hour, if the plate were one half of the temperature, or if *two hundred and eighty degrees*, the heating effect would be 800 units per foot per hour. Or, in other words, if the fur [illegible] worked at the same temperature as that of a *boiler* [illegible] would be substantially the same. See t [illegible] Walworth radiator: steam 250°, 636 cubic feet air raised 70° = 856 units per foot per hour. That the work of steam boilers and radiators can be greatly increased by increase of temperature, is true. And this is where the furnace-man has the steam-man at a disadvantage, and also his customer, when he sells him one foot of heating surface to do the work of three, which is only possible by raising the temperature of the plate and furnace and flues to *three times their proper and normal heat*; and to do this, he must *waste fuel in proportion.*

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*Ch [illegible]

The employment of cast or even wrought iron surfaces in stoves or furnaces with a fire on one side of the plate and *air* on the other, for protection of the plate and transmission of the heat, is very different than with similar surfaces when *water* is the agent of protection and transmission, the water being nearly one hundred times more efficient in receiving and conveying heat away from a plate than air; it is practically impossible to raise the temperature of iron or any other metal in contact with water any higher than the temperature of the liquid. In a steam boiler used for heating, the temperature of the shell or tubes would not exceed that of the water, or less than 300°.

Whatever the temperature of the furnace plate, the air is always lower, and continually losing the heat first acquired to the outer layers of air and to the pipes used to conduct it away. The difficulty of conducting the air away from the furnace is familiar to every furnace-man, and generally to most people who use this means of warming. The small furnaces with few pipes, short, and with vertical delivery, are perhaps the exception.

Where the furnace is large, the pipes numerous, of various lengths and heights, an equal work and delivery of the warmed air has not been found practical or possible except in the hands of skillful mechanics, and employing special devices for the needful equalization.

This, with other difficulties of moving warm air horizontally, has induced an application of what is called the combined hot-air and hot-water furnace, several of which are now on the market, and doubtless have advantages in sending a current of *water* to do the work at a distance, impossible to the air alone.

The matter of the equalization of pressure and delivery of warm air from a common heat chamber through pipes of different diameters and heights is one of the most difficult and delicate of all the problems which confront the heating engineer. It does not confront the average furnace-man or the average steam-man, because he never thinks of or seeks to provide for it. And yet it is not so difficult to understand, if *thinking* and *study* were any part of his business; generally they are not, and he cuts and fits for one house much as he does for another. The conditions are hardly ever alike, while the laws which govern heat an cold remain the same.

The delivery of warm air at different *vertical heights* is not so difficult to understand or provide for as horizontal delivery; yet this is often made a failure of, owing to a neglect of certain conditions inseparable from even *vertical* work, and from ignoring that other important question, *equalization of pressure in the furnace or heat chamber.*

The power to move and deliver warm air from the furnace in any direction is simply gravity, or, what may perhaps be plainer, *the difference in weight between the two columns of a fluid.* This is found to be proportional to the square root of the *different heights* of the columns multiplied by their *difference of temperature.*

Table No. 26 has been arranged to show this law for the lower temperatures of air in exit flues for purposes of heat and ventilation. It shows, moreover, that *height and temperature are the factors of power.* See also diagram No. 32.

In table No. 27, the size of the hot-air flues for steam or water surfaces is calculated by this rule, corrected by much experience, and the power is seen to be 25 per cent greater for each increase in height of a story of twelve feet. Assuming the temperature to be doubled, then, as in the case of furnace heating, the given sizes of pipes and registers could be reduced about one fourth.

Returning to the question of unequal pressure, in a warm-air chamber it may be seen to be due to the power absorbed by the higher pipes and freer delivery. That is, a pipe delivering air to the first floor at *two feet* of height will be weakened and sometimes crippled altogether by a pipe drawing from the same chamber and delivering *twelve feet* high to a second story, especially if this is the case where there is any reduction of the cold air supplied; and, even where there is abundance of cold air, there will still be a deficiency of pressure and air delivery from the lower pipe.

If, then, we desire, as we often do, to take pipes of different heights from the same heat chamber, the high ones must be reduced in size, or the heat chamber must be divided by diaphragms or distances, so that the high pipes cannot rob the lower ones.

In long heat chambers, as in indirect steam and water heating, a high pipe and a low one should not be taken from the same location. If they both must leave the chamber on the same side, the high pipe should extend horizontally inside the heat chamber to a point remote as possible from the lower delivery; thus the pressure in the chamber will be equalized, and the lower pipes will be equally efficient.

It will be seen that the above remarks on the supply of warm air to different localities from the same heating chamber apply to all systems, whether warmed by a furnace or by "indirect" steam and water radiators.

STEAM AND WATER FURNACES.

Passing from the consideration of furnaces with extended surface, the next method most closely allied to the preceding is by indirect radiators, where the air to be heated, instead of being admitted around the furnace, is allowed to enter a chamber containing a stack of radiators heated by steam or water, which is flowed from the boiler to the several parts of the basement beneath which the heat chambers are located.

While it is impracticable to distribute warm air long distances through horizontal flues, steam and water may be readily flowed in small pipes to any part of the building, thus allowing the heat chamber to be located immediately under the rooms to be warmed, and only necessitating a short flue for the delivery of air, extending from the chamber to the room above.

Besides the advantage of control over the position of the heat, indirect radiation affords the means of greatly increasing the area of the heating surface, with which the air comes in contact, by the subdivision of the radiators into small compartments, and the further extension of the surface of these by means of solid projections; the air admitted comes in contact with a large surface, and is uniformly heated without danger of vitiation by overheat, or by escaping products of combustion. Also the superior regulation of the cold and warm air, and the economy secured by a comparatively low temperature in the furnace, and the opportunity offered of supplementing the indirect system for rooms not easily reached, by direct radiators, all of which are peculiar to the indirect system of heating by steam or water.

It may appear to some readers that in looking for illustrations we select the old machines and methods rather than the later goods, that might, in the nature of the case, claim some superiority from recent discoveries and better applications.

We have seen, however, that while there have been advances in the method of construction and operation of the common hot-air furnace and in the steam and water boiler, that the later goods are but copies of the older, with perhaps a change of form and surfaces not always to the credit of the so-called improvement.

While the two following plates are familiar to the trade, there are others not in the steam or furnace business to whom these illustrations will prove acceptable, especially as they show about all the conditions attaching to the latest and most improved steam and water apparatus. The subject of house warming, however, will not be further continued here, as it will be taken up again later, under the head of *Ventilation*.

In the tables are found the data, both for supply of warm air (steam and water heating), also the amount that can be removed through flues to secure ventilation.

The first early and successful *combination* furnace was that of Samuel Gold, the first patent for which was granted June 21, 1869; reissue Feb. 16, 1882. See page 390.

Although this was perhaps the second earliest cast sectional boiler, it was the first in the field, and one especially its own — that of low-pressure steam heating applied to dwelling-houses and the smaller buildings; at least, this is where it has obtained its greatest success, and one unequaled by any other construction or device whatever.

Although now upon the market for about thirty years and practically unchanged in its general features, the demand is as steady and constant as ever, and, since the extinction of the patent, is manufactured by others than the original owners.

True, the first construction has been much improved upon by the drum and nipple connections, and later by an improved grate,* also by larger flues and better attention to mechanical details.

As the Gold sections are of the simplest construction, being little more than a flat oblong box of moderate dimensions, grouped together, the fire operating upon them and through the flues, as in a locomotive boiler, they have held their own against all comers, and appear likely to do so for years to come.

This success and the reason of it have been more or less of a mystery to the rival claimants for honors in the house-warming line, as also the efficiency and remarkable vitality of the indirect pin radiator by the same inventor.

That Gold's boiler had some witchery about it, there was no doubt; for, while purchased and handled generally by the "Trade" (so called),— persons mainly bred to various mechanical trades, as gas fitters, plumbers, tinsmiths, and galvanized iron workers,— they have, with the assistance and instruction of the manufacturers, set the boiler in all sorts of houses and conditions, and yet made good the claim to warm a dwelling more satisfactorily throughout the whole season when heat is required than any similar apparatus ever put on the market.

The secret of this uniform success is now no longer a mystery, and may be stated to consist, first, in the *combination of a water and steam agency in one apparatus;* the outside surfaces of the boiler furnishing (in the chamber) the water heat, when no steam was made, or making, and, second, in the liberal supply of [illegible]ir thus obtained throughout the dwelling.

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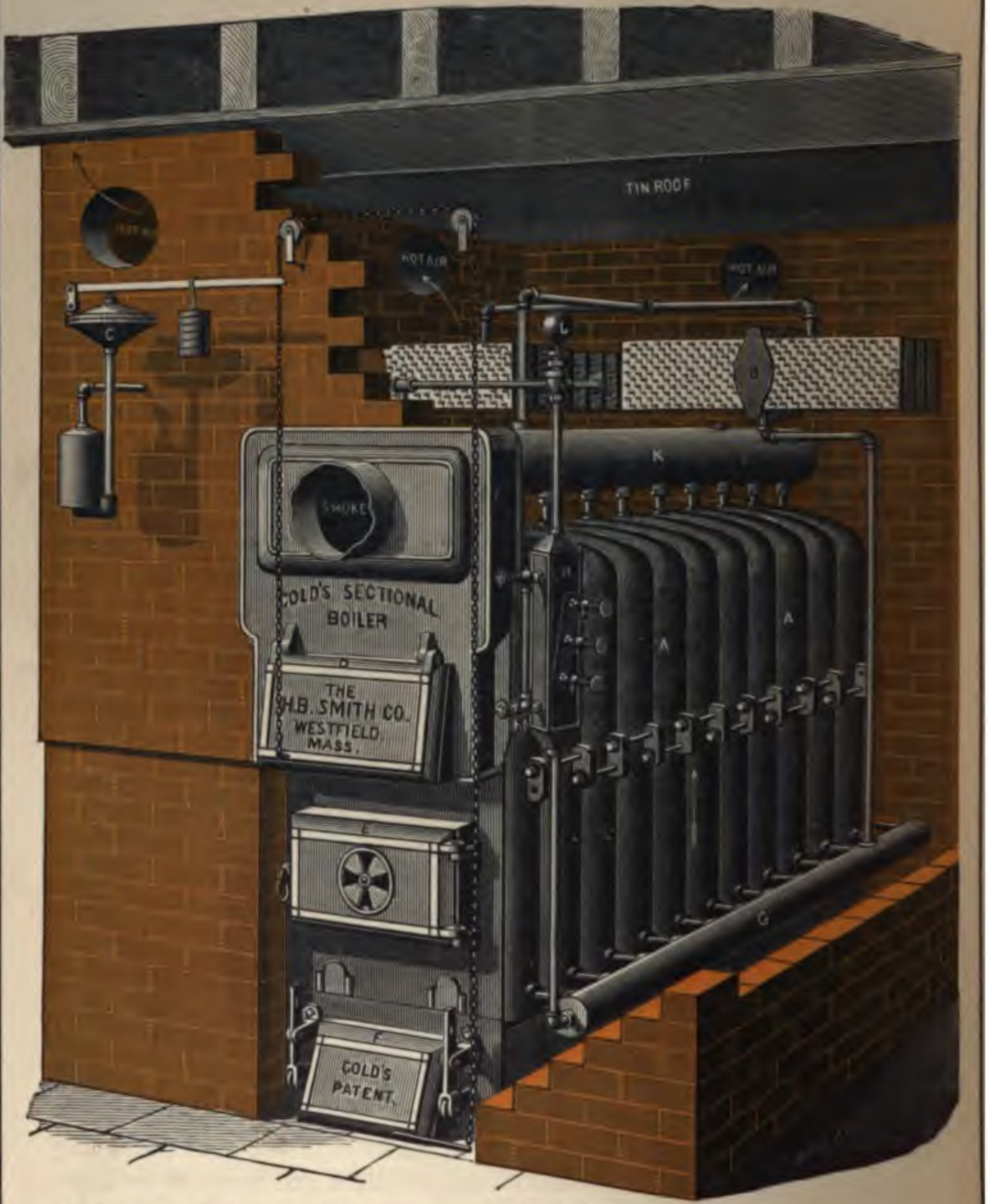
* Both originating with the author and to [illegible] ars of 1872.

PLATE No. 40.

*THE UNION STEAM AND WATER APPARATUS,

THE CHAMBER PARTLY REMOVED TO SHOW THE DETAILS.



A A are the Sections of the Boiler.
B B Stacks of indirect Radiators.
C Damper Regulator.
D Flue Door. **E** Feed or Fire Door.
F Ash Pit or Draught Door.
G Return Drum.
H Water Column with Gauge Glass.
J Safety Valve. **K** Steam Drum.

*The H. B. SMITH Co., Manufacturers, Westfield, Mass.

CHAPTER XXII.

STEAM AND WATER AS HEATING MEDIUMS.

OF the early history of steam heating and introduction of wrought-iron pipes into this country, we reproduce on the following page a cut, which did duty in a New York journal of the year 1841. At that date Mr. J. J. Walworth took possession of a small stock of wrought-iron pipe and fittings that had been sent to this country by James Russell & Sons of Wednesbury, England, which had been purchased by Mr. Joseph Nason, then in England.

This stock consisted of pipe of various small diameters, and in short lengths, with wrought-iron elbows, tees, and crosses.

No machine-work was attempted in the store, not even to the extent of cutting off or threading a piece of pipe.

The only method of furnishing a pipe measure to order, was to chalk out a rough diagram on the floor full size, and select the pipes of the necessary lengths to make up the required amount. At this date there was no other concern in the United States doing business of this kind.

About this time Morris, Tasker & Co., then stove and grate dealers, commenced making wrought-iron pipe in the basement of their store in Philadelphia. *This was the first wrought-iron pipe made in America.*

Other firms soon after entering the business of wrought-iron pipe manufacture, it was pushed on from one stage to another of development, including the butt and lap-welded joint, all made by machines, including the seamless drawn steel and brass tubes of almost any diameter and thickness, and so true and straight as to be fit almost for gun barrels, *which, by the way, were the first kind of iron tubes ever employed to convey gas, steam, or water.*

The application of steam to the warming of buildings in the United States practically began with Mr. Joseph Nason. He was not only the first to make the attempt, but was also the [illegible] improver, and adapter of much that is essential, and [illegible] the general arrangements and details of apparatus so [illegible] advantage of having been for a short time [illegible] London, about the year 1840.

And Mr. Nason's earliest endeavor in America was to adapt the Perkins system for hot water in small tubes for the warming of residences and other buildings.

The large extent of heating surface and the great strength presented by apparatus constructed of small and comparatively inexpensive wrought-iron tubes, and the facility thereby afforded for transmitting heat in any direction from a central source, are merits that lead to so rapid a development of this system of warming, that by 1860, or in less than twenty years, there were already many hundred establishments throughout America for the manufacture of the apparatus.

With the maturing and introduction of the system are associated the names of Mr. J. J. Walworth, of Boston, brother-in-law and partner of Mr. Nason; Mr. Gregg, of New York, Mr. J. O. Morse, of New York, Professor Mapes, of New York, who supplied a reliable steam trap; Mr Miles Greenwood, of Cincinnati, to whom is credited the arrangement of a nest or coil of vertical tubes connected by return bends; and Mr. Thomas T. Tasker, of Philadelphia, who introduced the first closed apparatus, *returning the water of condensation to the boiler.*

WROUGHT IRON
PIPES
AND FIXTURES OF ALL KINDS FOR
WATER, GAS, STEAM,
And other Mechanical Purposes.
PUBLIC COMPANIES AND INDIVIDUALS
CAN BE SUPPLIED WITH THE ABOVE BY
WALWORTH & NASON,
36 Ann Street, New-York.
☞ Strong Pipes for Perkins's System of Heating Buildings by a circulation of Hot Water; Steam Gauges and Steam Gauge Pipes; Stocks, Dies. and other Tools, &c. &c.

About one year after Mr. J. J. Walworth commenced the business in New York, Mr. Nason returned from England, and proposed to join him, and introduce what was known as the "Perkins hot-water apparatus," with which he had become acquainted in connection with Mr. Angier Perkins, of London. They accordingly came to Boston, and became associated in the summer of 1842, under the firm name of Walworth & Nason. They also did some *steam* heating with cast-iron pipes, using a patented right and left joint, the threads cast on both the pipes and at the coupling, and the joint made tight by a card-board gasket between the ends of the pipes, which had been squared off for that purpose. They soon after commenced to use small wrought-iron pipes for conveying steam, the first building warmed that way being the Eastern Exchange Hotel, at that time near what was later the terminus of the Eastern Railroad. During the years 1845 and 1846 the business was rapidly extended in cotton and woollen mills and other buildings at Manchester, Salem, Portsmouth, Lewiston, Fall River, and Providence.

The want of various new fittings and appliances was soon felt, and the firm set about supplying them, such as steam and gas fittings, cast-iron elbows, tee crosses, branch tees, hook plates, return bends, expansion joints, steam traps, etc.; also a better system of taps and dies, including the scroll plate. The angle valve was produced, and then followed the globe valve, substantially as it is now used. During all these early years of construction and development of the steam business, Mr. Nason took charge of the mechanical construction and Mr. Walworth of the outside engineering and superintendence.

The system of taper screw threads for the tube connections is believed to have been originated by Mr. Nason in 1846, at which time all threads were cut in a lathe. The celebrated Nason Radiator was also the work of his practical and inventive mind, but this radiator did not appear until the year 1862. The principal feature of this invention was a wrought tube, closed at the upper end, and having an inside diaphragm to promote circulation. The lower end was screwed into the radiator base. [This history is continued in Vol. 2.]

Before passing to the consideration of our next, and as we expect to show the best, medium for absorbing and distributing heat, we pause with some impatience, as it were, at the apparently lost time and effort already expended on other issues, which were, however, as seen, necessary to a connected and continuous review of our subject.

The employment of *water as a heat carrier* is important enough for a whole volume; and that it has received this credit and distinction at the hands of able writers makes the author's efforts difficult, as but a limited time and space are at his disposal, in which to discuss past, present, and possible uses of steam and water as heating agents.

Since, however, the writer's later application of water as a heating medium, both for large and small buildings, is based on his former and *distinctive* piping for steam, references and descriptions of this system are in order — more especially as many persons who have used and desire to use this *overhead* system do not know either its origin or its extensive introduction. In this connection we may note that, while "Appleton's Encyclopedia" gave the system due credit, later writers *treating of steam heating, and supposed to be informed, did not refer to it.* The *Sanitary Engineer*, answering a correspondent, either did not understand the question, or confused the old Gold's method of a single riser, supplying steam *upward*, and without any return, with the *overhead system* and *downward supply*, which their correspondent evidently *had in wind;* at any rate, as both the methods, the old and the new, are in reality a one-pipe application of steam to radiators, a distinction should have been made between them, where one was cited as old and entirely out of "fashion," *the other system being new and a noted success.*

The following copy of the original patent papers, with the letters from prominent heating companies, shows how the overhead method of piping was invented and regarded a few years ago; also that the writer's later application of water, under substantially the same conditions, originated in the same way. It may also be stated that all the parties on the list of buildings acknowledged the validity of the patents, and took out licenses to use this improved method of piping, also several others not on the list, who, for various reasons, did not extensively use the system. The author's personal applications of the system do not appear on the list.

There were other parties, principally at the West that, seeing the value of this method of piping, used it freely, some, perhaps, without knowing the ownership of the patents, while others who did know, objected on principle to paying royalties, when they could evade them by open infringement, or by some slight changes in the details of construction.

These patents were in 1877 put into the hands of an association, to work and manage with the author as Trustee; but as he had many other matters to attend to (the making a living among the rest) he could not properly follow up the outsiders, while they openly used or secretly infringed the reserved rights of the invention.

While steam as a heat-conveying medium is of importance and interest, it is not the author's intention to go into the general or particular applications of steam as a means of supplying heat or power, except, perhaps, in the way of comparison with other agents for the recovery and distribution of heat.

There are other reasons for confining our present effort under this heading mainly to but one agent, the first being the extensive use of steam in all classes of buildings, and the quite general knowledge now possessed, both of its utility and application.

The second reason is that several of the main and important issues relating to the safe and economical generation of steam have been considered in former chapters, while a very full and practical study has been made of all "heaters" familiarly known as "radiators," and their values under general and particular conditions.

We give this matter place and prominence here because, as stated, the *overhead system of steam distribution is the key to and the explanation of the overhead water supply single lines and single-valve system*, to be considered later.

See tables Nos. 10, 11, and 12, pages 323, 335, and 367.

Specification, forming part of Letters Patent No. 145,962, *dated Dec.* **30,** 1873. *Application filed April* 19, 1873, *and Reissue No.* 6,591, *dated Aug.* 10, 1875.

SYSTEM OF STEAM AND WATER PIPING FOR BUILDINGS.*

To all whom it may concern: —

Be it known that I, JOHN H. MILLS, of Boston, in the County of Suffolk and State of Massachusetts, have invented an improved system of piping for buildings to be heated by steam, of which the following is a specification: —

This invention relates to a new and improved method of piping for buildings to be heated with steam, whereby the cost of steam heat is reduced, and a more simple and efficient apparatus is supplied.

Prior to my experiments and the perfection of the invention now under consideration, the theory and practice of engineers and experts was reduced to the employment of two pipes, and, as far as possible, a separation of the steam and water resulting from condensation, thus rendering necessary two connections to each radiator and the employment of two valves, which required to be opened and closed simultaneously, or the radiators would become filled with water.

In the earlier stages of low-pressure steam heating a single pipe was tried, but the glaring defects of the arrangements (viz., supplying the steam upward against the descending water of condensation, and thereby causing noise and an impeded circulation in both pipes and radiators) soon caused the same to be abandoned.

The latter practice and that in vogue prior to my invention (viz., the employment of two pipes, one to supply the steam, and the other to carry off the water of condensation), while greatly increasing the cost, has not entirely removed the conflict of the elements thus brought into juxtaposition; for steam, air, and water will not move harmoniously together until their relative specific [illegible] considered and provision made therefor.

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*See drawing of [illegible]

Under my system no conflict is possible; for the steam, being conducted from the generator through one or more vertical mains to a point above the heating devices, and from thence distributed downward, is always on the top of the denser and heavier elements, which, thus arranged, move on in harmony with the law of gravity, and without impediment, both in their passage from the radiators and in their return to the generator. It will be also evident to those at all conversant with the operation of steam heating that, once having conducted the steam to a point above the radiators, and arranged for the escape of the air at the lowest (but above the water-line of the boiler), the question of a perfect, noiseless circulation would be no longer a doubtful one.

A steam generator of any suitable character is placed in the cellar or basement of the structure to be heated; affixed to such generator is a main supply pipe or conduit, which rises vertically and extends to a point in the building above or near which the highest radiator or coils are to be located. A steam radiator is placed in each or any of the stories of the structure; while a pipe extends from the upper part of the main supply pipe, horizontally or slightly descending, to the side or other wall, thence directly downward to the lower part of the basement or cellar in which the generator is placed, and discharges into such generator. A pipe extends from the branch or return pipe to, and communicates with, each radiator at the upper part thereof, while the outlet or escape pipe of such radiators, leading from the bottom thereof, and for carrying off the water of condensation, connects with and discharges into the said drop pipe, as described.

At a point on the down or return pipe, below the first or lowest radiator, and above the water-line of the boiler — as, for instance, within the basement — I arrange a valve designed to permit the escape of air. This valve, when the apparatus is put in operation, is left open; so that the air expelled from the piping, and from the several radiators by the advancing steam, shall find vent at this point. The air will have been discharged when the steam begins to blow through the discharge pipe, at which time the valve should be closed. Thus I am enabled to provide one common vent for all the air that may be contained in the piping and radiators, and, furthermore, to locate this vent at a point where the foul air and noxious gases can be got rid of without inconvenience to the occupants of the building. Heretofore it has been customary to provide each radiator with a vent, and the air has been discharged directly into the room in which the radiator was located.

The advantage of my venting arrangement, which is rendered practicable by my system of steam piping, is therefore apparent. A suitable coupling may be attached to the main supply pipe in each story or division of the structure, the same being provided with a valve; to these couplings a hose may be attached, in case of fire, or through which steam may be discharged directly into the apartment, without the intervention of hose.

The operation of the above-described method is as follows: Steam under pressure from the generator or boiler is conducted directly upward through the main supply pipe until it reaches the return pipe, down which it descends until it reaches the connecting pipe of each radiator whose valve is open. After circulating through the same, and parting with its heat, it is condensed; and the resultant water flows through the outlet, or drip pipe, into the return pipe, and directly down the latter, without hindrance or check, where it is discharged into the generator.

Having described my invention, what I claim is:—

1. *The herein-described system of steam heating, the same consisting in the combination of one or more main pipes, conveying the steam without distribution to a point above the radiators, with branch piping conveying the steam downward, and serving at one and the same time to supply steam to and conduct the water of condensation from the radiators, the steam, air, and water moving together in one direction towards the boiler, as described.*

2. *In a system of steam heating comprising an overhead supply, the combination of the radiators or coils with the branch or return piping entering below the water line of the boiler, as described.*

3. *The combination, with a system of steam piping and radiators connected therewith and operating as described, of an air vent or valve located on the branch or return piping, at a point below the first or lowest radiator, but above the water line of the boiler, as described.*

JOHN H. MILLS.

F. P. HALE,
F. C. HALE, } *Witnesses.*

OFFICE OF THE

WALWORTH MANUFACTURING COMPANY,

16 OLIVER STREET.

BOSTON, Aug. 18, 1877.

MR. JOHN H. MILLS,—

Dear Sir: In reply to your inquiries as to our opinion of your new and improved method of constructing steam-heating apparatus, to which our attention was called some four years since, where the supply of steam from above, working the steam, air, and water in one pipe, forward and downward toward the boiler, with a single connection and valve to each radiator, we then expressed the opinion that it was novel and correct in principle. We are of the same opinion now, after testing it fully in large and small buildings, and under varied conditions, with upright and horizontal pipes.

It has proved equally successful in large buildings, as proved in the Columbus Hospital for the Insane, where it is introduced with perfect success; the Memorial Hall at Cambridge; the Clarke Institute at Northampton, and others.

The new method is simple and easy of construction, less expensive. giving great satisfaction to the users, as well as to those who construct the apparatus.

That we have taken a large interest in your company, and are working under a license from it, may be assurance to you of our full endorsement of the new system, which has only to be tried to convince all of its great value.

Yours truly,

WALWORTH MANUFACTURING COMPANY.
BY C. C. WALWORTH, *General Manager.*

COLUMBUS, O., Jan. 19, 1876.

MR. JOHN H. MILLS,—

Dear Sir: In reply to your inquiry as to the probable difference of cost in the erection of the steam-heating apparatus at the Central Ohio Lunatic Asylum, between the usual method of using a double connection for the radiator and the "overhead supply," or single connection, for which you hold certain patents, I will say that I am unable at present to state the sum definitely; but, to the best of my judgment, it is a saving of at least two thousand ($2,000) dollars—possibly more, but cannot be far from that sum.

I am fully conversant with your different methods or systems of running pipe, have adopted them, and am well convinced the economy and other advantages of the system will lead to its very general introduction.

Many of the disadvantages of the "double-pipe" system are avoided, and it is so much more simple that it commends itself to any intelligent man at once.

Yours very truly,

LEVI R. GREENE, *Con. Eng.*

WESTFIELD, May 31, 1877.

MR. JOHN H. MILLS,—

Sir: Your "System of Steam-Piping" has been adopted by us on several jobs in Providence, and with satisfactory results. Have the same system in use in a portion of the Normal School Boarding-House at Westfield, Mass.; this gives excellent satisfaction, and the fact that but one valve on each radiator is all that is necessary, is very much in its favor. We have no doubt but it will be generally adopted by first-class concerns on first-class work, as soon as its merits are understood.

Yours truly,

H. B. SMITH & Co.

FRED'K GRINNELL, *President.* J. C. HARTSHORN, *Treasurer.*

OFFICE OF THE

PROVIDENCE STEAM AND GAS PIPE CO.,

CORNER OF EDDY AND PINE STS.

PROVIDENCE, R. I., June 5, 1879.

TO WHOM IT MAY CONCERN:

About one year since, we commenced the erection and construction of low pressure steam-heating apparatus by the "*Overhead System*" of distribution, designed by Mr. J. H. Mills, of Boston, who has made the plans, estimates, and specifications for the work and contracts we have executed under these patents. Up to this time, although much of our large business has consisted of high pressure and mill heating, we had not given much attention to heating public, commercial buildings or private dwellings, mostly because of the uncertain result attained by the most experienced firms doing this work. We say "uncertain results" because nearly every person seemed to have a different "idea" as to how such should be constructed.

No general principles being acknowledged or put into practice, no uniform results were obtained. But looking into the "Overhead System" referred to, we saw at once that, if these principles could be successfully applied and covered by patents, then might the heating of buildings by low pressure steam be reduced to a "science," valuable alike to the constructor and the owner of buildings.

Our first work and estimates submitted to the architects, Messrs. Stone & Carpenter, for the new State Prison Building at Cranston, R. I., were approved by them and accepted by the commissioners. Cubical space heated, 1,368,488. Radiation, 10,000 feet. Amount of contract, about $13,000.

Later we warmed the Old Ladies' Home, Brownell Building, Beckwith Building, Palmer Block, and one or two private residences, amounting to over 2,000,000 cubic feet of space and 18,000 feet of radiation.

All of this work, with one exception, had a winter's test, some of it a hard one; as with the Beckwith Building, which was started with the thermometer below zero and ran through the whole winter with only cotton cloth for the doors and windows; and it was remarked by practical men that no other system of piping could have remained operative a single day, much less have held steam on the buildings night and day.

In this connection we would say that in all the above work, we used the cast-iron sectional boilers, designed by Mr. J. H. Mills, and manufactured by H. B. Smith, of Westfield.

The whole of this varied application of the new system has given entire satisfaction, both to the owners of the buildings, the architects, and to ourselves, so that we have taken a license for this section, and also invested in the stock of the Association formed to place this system in the hands of leading steam-heating firms in the country.

F. H. MAYNAR

Extracts from the Report of the Real-Estate Commissioners of the Young Men's Association of the City of Buffalo, Feb. 26, 1883, on the Heating of their Building — 600,000 Cubic Feet.

The board, after carefully considering all the plans and proposals, decided to call in to their aid two disinterested experts, and to employ them for the purpose of deciding on the merits of the various plans submitted. This was done, and the board met the experts so employed on several occasions, and finally decided to accept the bid of Mr. John H. Mills, of this city. This bid was to do the work for $6,500, and was the lowest bid presented to the board, the highest being $14,000. The contract of Mr. Mills was signed and the work was commenced about the 10th day of September, 1882, and was continued with great enterprise and industry by Mr. Mills until the first day of November, 1882, when steam was first raised in the boilers and the heating of the building was first begun.

The method of distributing the steam adopted by Mr. Mills, and for which he has a patent, is by the *overhead or single-pipe system*, in which the steam is conducted by a single main pipe directly upward to the highest point of supply, namely to the ceiling of the fourth floor and to the front of the building, a horizontal supply line being carried around the outside wall for the supply of the vertical lines and radiators on the several floors, the water of condensation following directly down to the basement, where it is gathered in a general line suspended from the ceiling, the water being thus returned to the generators without the aid of pumps or traps. The radiators for the entire work are of cast iron, Reed's patent, with a vertical tube and an open base, and are of the sizes and surfaces required with the pipe to warm the various rooms in which they are located up to a temperature of 70° Fahr. in zero weather. Two boilers have been placed in the boiler-room. They are the Mills sectional safety generators, and are each rated at forty horse-power, having a combined surface of one thousand square feet and forty square feet of grate, and are set in substantial brickwork with ornamental fronts, and are fitted up with the regular and necessary trimmings, such as safety valves, blow-off cocks, etc., etc.

The board are greatly pleased with the operation of the system. It does the required work satisfactorily and with great economy. It has been examined by many experts, and has been pronounced the most perfect system for steam heating ever erected in this city. Only one boiler has been used as yet at any time, and that is capable of, and does furnish all the steam required to heat all the buildings. Steam can be raised and distributed through all the buildings from cold water in twenty minutes. Its introduction has not marred or disfigured the buildings in any manner. The cost of this apparatus has been very small, compared with the work which has been done, the quantities of materials which have been furnished, and the cost of similar work done in other places. The gentlemen who offered to introduce their systems into the building at a price of $14,000 could do no more than is being done by this system, which has only cost $6,500. The experts who examined the work and on whose certificate only the contractor has been paid, have certified "*that it is perfectly safe, well built, conveniently constructed, made of first-class material, durable in all its parts, and that it is capable, without danger to its boiler or radiators, of heating the various portions of the building up to seventy degrees in zero weather.*"

The board would be pleased to have the members of the association examine the apparatus and its working, as they are sure that they would be surprised at the large amount of heat generated with the small amount of fuel consumed, and also at the perfect and noiseless working of the whole apparatus.

J. M. HUTCHINSON,
CHARLES A. SWEET,
ROBERT P. WILSON,
HENRY BULL,
JOHN L. WILLIAMS,

Commissioners of the
Board of Real Estate,
Young Men's Association.

PARTIAL LIST OF BUILDINGS

WARMED BY THE

"MILLS" OVERHEAD SYSTEM OF STEAM DISTRIBUTION.

[Patented 1873, 1874, 1875.]

Buildings.			Cubic Feet.
Hotel Alexandria	Boston, Mass.	**By the Walworth Manuf'g Co.**	300,000
" Bristol	" "		150,000
" Leeds	" "		50,000
" Edinburgh	" "		200,000
" Hofman	" "		652,000
Store, Jordan, Marsh & Co.	" "		600,000
" Jordan, Marsh & Co	" "		400,000
" Fairbanks & Co	" "		140,000
" Paul & Co	" "		100,000
Howard National Bank	" "		8,000
Double Dwelling	" "		60,000
Medical Library	" "		40,000
Hotel Comfort	Roxbury, Mass		273,000
Mansion House	Greenfield, Mass		120,000
Shillito Building	Cincinnati, O		3,300,000
Memorial Hall, H. C	Cambridge, Mass		1,100,000
Gymnasium	" "		200,000
State Prison	New Hampshire		300,000
County Almshouse	" "		80,000
Peabody Museum	Cambridge, Mass		96,000
Warren Savings Bank	" "		200,000
Central Lunatic Asylum	Columbus, O		3,000,000
Ohio Tool Company	"		26,000
Jacob Sleeper	Boston, Mass		295,000
Store, W. W. Boardman	Lowell, Mass		10,000
Frye Block	Lewiston, Me		80,000
Porter Block	Grand Rapids, Mich		450,000
C. P. Crowther	St. Louis, Mo		977,000
Jones McCune	Columbus, O		239,000
Clarke Institution	Northampton, Mass		409,000
		Thirty buildings,	**13,955,000**
State Prison,	Cranston, R. I.	**Prov. Steam and Gas Pipe Co.**	1,400,000
Brownell Building	" "		290,000
Old Ladies' Home	" "		206,000
St. Mary's Convent	" "		50,000
Hotel Dorrance	" "		100,000
Hotel Palmer	" "		100,000
Normal School	Westfield, Mass.	**The H. B. Smith Co.**	200,000
Congregational Church	" "		220,000
Two School Buildings	Rockville, Conn		270,000
Henry's Opera House	" "		125,000
Citizens' Block	" "		200,000
Anthony Building	Providence, R. I		100,000
R. I. Trust Co. Building	" "		90,000
Amherst House	Amherst, Mass		90,000
Hartford Fire Ins. Co.	Hartford, Conn.		100,000
High School	Manchester, N. H.	**Thos. A. Lane Co.**	180,000
Dunlap Block	" "		149,000
W. G. Perry	" "		24,000
City Hotel	" "		50,000
Block	Peoria, Ill.	**Decker, Hibbard & Co.**	546,000
Odd Fellows Hall	St. Johns, N. B.	**Wisdom & Fish,**	145,000
St. Andrew's Church	" "		380,000
Store, W. H. Glenny & Sons	Buffalo, N. Y.	**Hart, Ball & Hart,**	200,000
Store, Weller, Brown & Mesmer	" "		300,000
Orphan Asylum	" "		200,000
City Hospital	" "		150,000
1st Presbyterian Church	St. Catharine, Ont		161,000
Congregational Church	Jamestown, N. Y		180,000
College Buildings	Richmond, Va.	**E. H. Cook, Elmira, N. Y.**	400 000
School Building	Geneva, N. Y		
Office Building	" "		
Store Building	Elmira, N. Y		
		Thirty-two buildings,	

NOTE.— The author's work is not included in this

For plans of the piping above referred to, see page

*HEATING CITIES BY STEAM.

"The advantages of a steam supply from a central station for the buildings in a city or village, and even for the detached buildings of hospitals and other public institutions in a park, are very evident, and such a system has in the past been many times suggested as desirable. About fifteen years ago Birdsall Holly, of Lockport, N. Y., made experiments in his yard to show the loss of heat in transmitting steam through an underground conductor, the outcome of which was a practical system adapted for street distribution, in which stuffing-boxes were arranged at regular intervals of about one hundred feet and anchored fast, so as to preserve their location and permit the sliding sleeves to move in and out freely in a line.

"Outlets were also provided in chambers back of the stuffing-boxes for the attachment of service pipes to distribute the steam to buildings; so the supply was from stationary points, the same as if boilers were located at those points. Simple as these improvements seem to have been, compared with previous arrangements of interior steam piping, they form an important element of the success of modern systems of steam distribution in cities. The large steam plant of the New York Steam Company has been built up under the direction of Charles E. Emery, Ph. D., on the principle of the Holly patents above described, but without the use of one of the Holly details; and the steam from boilers of twelve thousand horse-power is now being delivered at a pressure of eighty pounds and upwards for power, as well as heat, through some five miles of large steam pipes, some of which extend three fourths of a mile from the boiler station.

"The first station of the company was located on Greenwich Street, between Dey and Cortland Streets. The building was designed to contain sixteen thousand horse-power of boilers of the Babcock & Wilcox type.

"Some idea of the magnitude of the work can be obtained from the statement that there are already in position in the first station one sixteen-inch pipe, one fifteen-inch pipe, and one eleven-inch pipe, with only part of the capacity of the building yet utilized, and that it is expected to put in in addition one thirty-inch pipe, to keep up the pressure at a distance as the demand increases.

"It has been found that the pipes can be so protected in practice that the loss of condensation will be a very small proportion of their carrying capacity. Experiments were made before the plant of the New York Steam Company was built, that showed that mineral wool of ordinary quality furnished very nearly the same resistance to the passage of heat as the same thickness of hair felt, and that the better qualities were equal or even superior in this respect to hair felt.

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*C. E. Emery.

DOMESTIC STEAM HEATING SYSTEM.

1st. In a gravity return system of pipes and radiators there are *three* elements always present,—*water*, *air*, and *steam*,—due provision for which must be made, and *separation effected*, before the heat agent, steam, can be *successfully circulated* or satisfactorily accomplish its work.

2d. In a *steam* or vapor heating system, the pipes and radiators (and a part of the boiler), when below a certain fixed temperature, are *always* full of air, which must be expelled by pressure, through various devices, before circulation can take place, and requiring an internal pressure greater than the external before the air can be expelled, permitting circulation.

3d. This necessitates *three* lines of piping,—a *steam-supply* pipe, an *air-escape* pipe, and a *water-return* pipe,—while all these various pipes must be graded to conform to their several and *different uses.*

4th. In a steam or vapor heating system, almost any kind of pipes and radiators will answer (with the above attachments), as steam under pressure will enter vertical pipes or radiator tubes having closed ends,—as in the Nason and Bundy and other similar radiators,—a provision being made for the air to fall before the steam to the base, and be expelled through the air devices; and it is just this ability to vent the air from the tubes which gives these radiators and constructions their efficiency as *steam radiators;* but they are worth *nothing* as *water* radiators, because water will not enter and fill their tubes, the *air* preventing; and, therefore, water and steam systems ARE NOT the same thing, "differing only in degree of the heat-conveying power," as stated in a late letter from the Patent Office.

5th. A system of steam heating involves a boiler but *partially* filled with water, the maintenance of a water line, and that all supply lines and radiators shall be located *above such line*, to be freed from the water of condensation, all parts of the system being maintained at an *equal* pressure, to insure the automatic return of the water of condensation to the boiler, if the return is automatic.

6th. In a system of heating by steam, the real agent is the *latent heat* absorbed while the *water* is being converted into a *vapor*, and to be obtained only while the water is being held under a pressure above the atmosphere, where such conversion takes place. To obtain this stored or latent heat the vapor must be condensed; *condensation destroys the pressure* and thus the circulation, air or water at once taking the place of the vapor, *while all the heat generated in the* [illegible] *the temperature of the boiling water* passes away to [illegible] lost.

This may amount to one quarter or one third [illegible] other losses due to a partial derangement and [illegible]

DOMESTIC WATER-HEATING SYSTEMS.

We have not time here in which to enumerate the salient and good points of a fluid-circulating *gravity return* apparatus when under its best conditions, but a few of them may be mentioned:—

1st. A heat agent obtained at the least possible cost, and that is always silent in operation.

2d. One that is under perfect control, and that may be flowed from the boiler to so nearly meet the varying demands of the weather as to require little or no adjustment at the radiator in the rooms heated.

3d. That water has many advantages as a heat-conveying medium, may be said without any reservation; and that it is absolutely the best agent for carrying heat either long or short distances, will, we think, be clear after an examination of some other conditions of circulation than those advocated by writers.

Having said this, it does not follow that a water apparatus can have no defect, and that it will surely and positively satisfy all that try it under the many and singular forms and guises under which it has been, and will still continue to be, offered to the public. Just at the present time water heat is in great favor, due to several causes; first of which are its many good qualities, and second the fact that water is the heat that will always hold its tongue, and not "blab" out every defect which the fitter or contractor made in its first conception and later execution. A steam apparatus will always "squeal" on the fellow that put it in; and at this late day so much is known of the proper and rational construction, that it is not so easy to cover up false tracks, as with the more modern and less understood water plant.

Still it may be said, and ought to be easily understood, that a water apparatus may be so misconstructed as to be a failure, both as to operation, efficiency, and economy. Heating apparatus of all kinds,—*hot air*, *hot water*, or *hot steam*—are not necessarily a success or a failure *because belonging to either system*, but really and simply because they have had more or less brains engrafted and transferred into them by the designer and engineer.

Establish any rational standard of construction, operation, and results for either system, and then compare the failures of each to reach such a standard, and I do not know on whose shoulders—the steam, the water, or the furnace men—the sword would fall with greatest force.

The crude work is of course being offered and done in the dwellings and for domestic uses, where really one would expect the best. This is mainly because the business of furnishing small portable apparatus is in the hands of a few people not yet educated up to the demands in this line, but fully aware of the ignorance of the average householder, and keenly alive to the profit that may be derived from such conditions.

RECAPITULATION WATER AND STEAM SYSTEMS.

1st. In a water heated or heating system of pipes and radiators, there is but ONE element present after the apparatus is ONCE filled or put to work. This element, being a liquid, fills all spaces, and closes them against the entrance of the air.

2d. In a water heated or heating system of pipes and radiators, the motive power is NOT PRESSURE obtained from the boiler (as in a steam system), BUT A DIFFERENCE OF PRESSURE IN THE PIPES AND THE RADIATORS DUE TO DIFFERENCE OF TEMPERATURE; and the power to circulate from and to the boiler is obtained FROM THE RETURN rather than the SUPPLY pipe.

Increasing the work increases the circulation, and therefore the heat (provided the generator will meet the increased demand).

3d. In a water heated and heating system, it is essential that there shall be a *cross connection* between all vertical tubes AT THEIR TOP ENDS; THAT THE CIRCULATION, after entering the radiator, shall be DOWNWARDS, thus DISTINGUISHING a WATER from a STEAM radiator. A radiator adapted for a water circulation will circulate steam, but a steam radiator with single vertical tubes will not circulate water.

4th. In a water-heating system there is no water line maintained, nor any particular grade of pipes or location of radiators above such line, and no EQUAL pressure necessary to insure circulation from and return to the boiler; in fact, the greater the DIFFERENCE OF PRESSURE between SUPPLY and RETURN lines, the more rapid the circulation, and efficient the heating surfaces.

CONDITIONS AND RESULTS.

STEAM SYSTEM.	WATER SYSTEM.
THREE ELEMENTS INVOLVED.	ONE ELEMENT INVOLVED.
Boiler pressure ESSENTIAL.	Boiler pressure NOT ESSENTIAL.
Equal “ “	Equal “ “ “
A water line “	A water line “ “
Grade of pipes “	Grade of pipes “ “
Fixed temperatures “	Fixed temp'tures “ “
Heat only with pressure.	Heat without pressure.
Any radiator available.	Special radiators required.
All heat below 212° *lost.*	[illegible] *nerated available.*
Available heat LIMITED.	[illegible] t UNLIMITED.
Circulation not always silent.	[illegible] d continuous.
Increased duty weakens circula[illegible]	[illegible] es circulat'n.

Economy, water 100 [illegible] t.

Before entering at length on the construction of apparatus for the distribution of heat by a water circulation, it seems desirable to examine briefly the nature and capacity of the elements employed.

The following table, No. 14, is, as seen, a list of all the essential elements pertaining to *steam or water under heat*, while passing through the same ranges of heat and of pressure, or from one to one hundred pounds; the key or factors from which each column is made up appearing in small type at the head.

Column A is the pressure, B is the temperature of water or steam, C the latent heat, D the total heat of steam from water at 32°, E the cubic feet of steam, and F the weight of a cubic foot.

Units of Heat per Cubic Foot. In column G it will be noticed that the 44 units credited are made up from the *total* heat actually absorbed from water at 32°; whereas the steam, in condensing to water, would give out only its *latent* heat, *thirty-five units, as underscored.* By the same *analysis and reasoning, the water in cooling, say thirty degrees, would release only about one thousand seven hundred and ninety-five units, the water heat being thus fifty times greater than the steam at the same temperatures.* This is for a reduction of 30°; if cooled 60°, the heat is double that stated.

By comparing the figures in columns G and H, it will be seen that the heat contained and conveyed by one cubic foot of water, and by a cubic foot of steam at the same temperatures, *is two hundred times* greater in the former case than in the latter for temperatures such as are ordinarily used in heating by low-pressure steam and hot water.

These figures also represent the amount of heat that is in the pipes and radiators, when two similar apparatus are filled, the one with water and the other with steam, at the same temperatures.

In the following diagram, No. 21, the conditions of *steam* and *water* shown by table No. 14, are illustrated.

Figure 1 shows the volume of the steam and the changes it undergoes as pressure increases from 1 to 100 pounds, and from 212° to 338°. Figure 3 shows the proportion and relation which *sensible* and *latent* heat bear to each other at the same temperature. Figure 2 illustrates the condition of water if held liquid and passing through temperatures from 100° to 280°. The upper section in red shows the expansion effected in 1,000 gallons of water raised from 60° to the different temperatures shown, and spaces required in an expansion tank of any heating apparatus, if we do not desire to add any pressure in the pipes other than that due to the vertical heights of the columns noted. The larger figures (right of figure 2) show the pressure of any column of water from 10 feet high (4.33 pounds) to 100 (43.31 pounds).

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* See Charles Hood on Hot Water, page 65.

TABLE No. 14.

Pressure, Temperature, Sensible, Latent, and Total Heat of Steam and Water per Lb. and per Cubic Foot, the Weight and Relative Volumes of Steam from 212° Far. to 338 = 100 lbs. to the Square Inch. The mechanical equivalent of the heat in steam is 772 X D.

	A	B	C	D	E	F	G	H	A	B	C	D	E	F	G	H	
	Gauge Pressure per Square Inch.	Temperature of Steam.	Units per lb.		Cubic Feet of Steam from 1 Cubic Foot Water, Density 62.355.	Weight of Cubic Foot Steam.	Units per Cubic Foot.		Gauge Pressure per Square Inch.	Temperature of Steam.	Units per lb.		Cubic Feet of Steam from 1 Cubic Foot Water, Density 62.355.	Weight of Cubic Foot of Steam.	Units per Cubic Foot.		
			Latent Heat of Steam = 1115.2 − (.708×B).	Total Heat of Steam from Water at 32° = 1081.4 + (.305×B).			Total Heat of Steam from Water at 32° = F×D.	Total Heat of Water from 32° = Weight of Cubic Foot×(D − C).			Latent Heat of Steam = 1115.2 − (.708×B).	Total Heat of Steam from Water at 32° = 1081.4 + (.305×B).			Total Heat of Steam from Water at 32° = F×D.	Total Heat of Water from 32° = Weight of Cubic Foot×(D − C).	
*	0	212	966	1146	1640	.0380	44	10770	50	298	904	1172	407	.1531	179	15410	*
2.8°	1	215	963	1147	1544	.0404	35	1795	51	299	904	1172	401	.1553			1°
	2	219	960	1148	1456	.0428	Steam.	Water.	52	300	903	1173	394	.1575	Steam.	Water.	
	3	222	958	1149	1378	.0452			53	301	902	1173	387	.1597			
	4	224	956	1150	1310	.0476			54	302	901	1173	384	.1619			
	5	228	954	1151	1247	.0500	58	11710	55	303	900	1174	379	.1641	193	15720	
	6	230	952	1152	1190	.0524	47	1800	56	304	900	1174	374	.1663			
	7	232	950	1152	1138	.0548			57	305	899	1174	369	.1685			
	8	235	949	1153	1089	.0572			58	305	898	1174	364	.1707			
	9	237	947	1154	1048	.0596			59	306	897	1175	360	.1729			
	10	239	946	1154	1008	.0620	72	12310	60	307	897	1175	355	.1752	206	15910	
1.75°	11	241	945	1155	969	.0643			61	308	896	1175	350	.1775			.8°
	12	244	943	1155	936	.0666			62	309	895	1175	346	.1797			
	13	246	941	1156	904	.0689			63	310	895	1176	342	.1819			
	14	248	940	1157	875	.0712			64	311	894	1176	338	.1841			
	15	250	937	1157	846	.0736	85	12950	65	312	893	1176	334	.1863	219	16040	
	16	252	936	1158	820	.0759			66	313	893	1176	330	.1885			
	17	253	935	1158	796	.0782			67	314	892	1177	326	.1907			
	18	255	934	1159	774	.0805			68	314	891	1177	322	.1929			
	19	257	932	1160	743	.0828			69	315	891	1177	319	.1951			
	20	259	931	1160	732	.0851	99	13430	70	316	890	1177	315	.1973	232	16350	
1.5°	21	260	930	1161	713	.0874			71	317	890	1178	312	.1995			.8°
	22	262	929	1161	694	.0898			72	318	889	1178	309	.2017			
	23	264	928	1162	676	.0922			73	318	889	1178	306	.2038			
	24	265	927	1162	660	.0945			74	319	888	1178	302	.2060			
	25	267	926	1163	644	.0967	112	13840	75	320	888	1179	299	.2082	245	16550	
	26	268	924	1163	630	.0990			76	321	887	1179	296	.2104			
	27	270	923	1164	615	.1013			77	322	887	1179	293	.2126			
	28	271	922	1164	602	.1035			78	322	886	1179	290	.2148			
	29	272	921	1165	589	.1058			79	323	886	1180	287	.2170			
	30	274	920	1165	576	.1082	126	14260	80	324	885	1180	284	.2191	259	16740	
1.3°	31	275	919	1165	564	.1104			81	325	885	1180	282	.2212			.7°
	32	277	918	1166	553	.1126			82	325	884	1180	279	.2234			
	33	278	917	1166	542	.1149			83	326	884	1180	276	.2256			
	34	279	916	1166	532	.1172			84	327	883	1181	273	.2278			
	35	281	916	1167	521	.1195	139	14560	85	328	883	1181	271	.2300	272	16870	
	36	282	915	1167	512	.1217			86	328	882	1181	268	.2322			
	37	283	914	1168	503	.1239			87	329	882	1181	266	.2344			
	38	284	913	1168	494	.1262			88	330	881	1181	264	.2366			
	39	285	913	1168	485	.1284			89	330	881	1182	261	.2387			
	40	286	912	1169	476	.1307	153	14770	90	331	880	1182	258	.2408	285	17080	
1.15°	41	288	911	1169	468	.1329			91	332	880	1182	256	2429			.66°
	42	289	910	1170	460	.1351			92	333	879	1182	254	.2450			
	43	290	910	1170	453	.1373			93	333	879	1182	252	.2471			
	44	291	909	1170	446	.1396			94	334	878	1183	250	.2492			
	45	292	908	1171	439	.1418	166	15170	95	334	878	1183	248	.2514	297	17180	
	46	294	908	1171	432	.1440			96	335	878	1183	246	.2536			
	47	295	907	1171	426	.1463			97	336	877	1183	244	.2558			
	48	296	906	1172	419	.1486			98	336	877	1183	242	.2579			
	49	297	905	1172	413	.1509			99	337	876	1183	240	.2601			
									100	338	876	1184	238	.2622	310		

* The average rise in temperature for each one lb. rise in pressure is bracketed in margins.

DIAGRAM No. 21.

Passage of Water and Steam through Similar Temperatures. (Figure 1, to accompany Figure 3 and Table No. 14.)

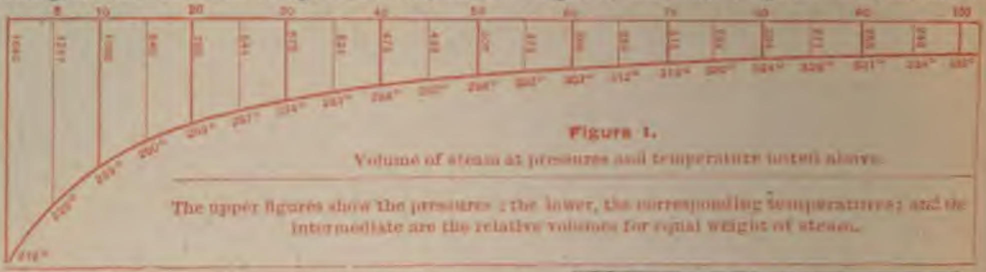

Figure 1.

Volume of steam at pressures and temperature noted above.

The upper figures show the pressures; the lower, the corresponding temperatures; and the intermediate are the relative volumes for equal weight of steam.

A. B. C. D. represent columns of water, 1,000 gallons each, heated from 40° to the temperatures shown.
The red section shows increased volume due to expansion.

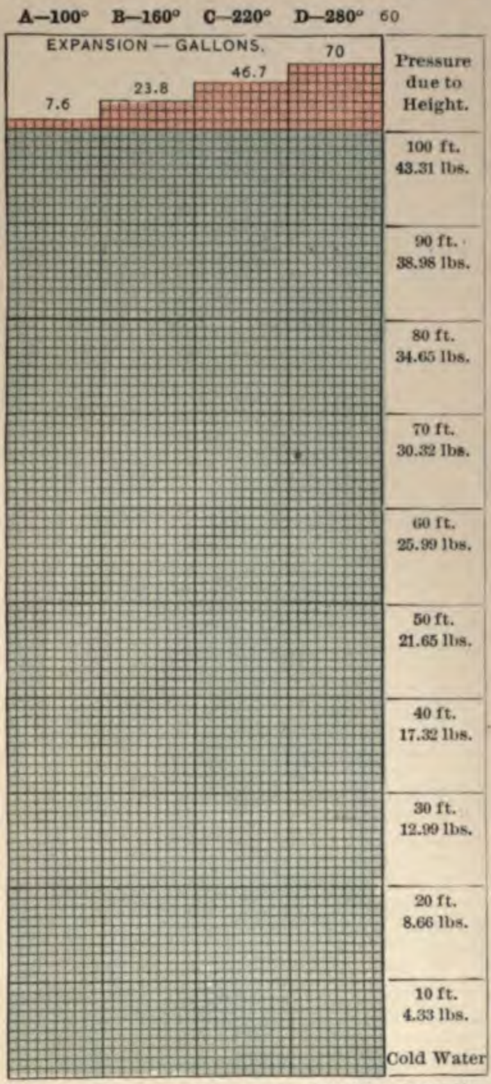

FIGURE 2. Expansion of water under the heat shown.

Each Small Square = 1 Gallon. Each Division, 100 Gallons.

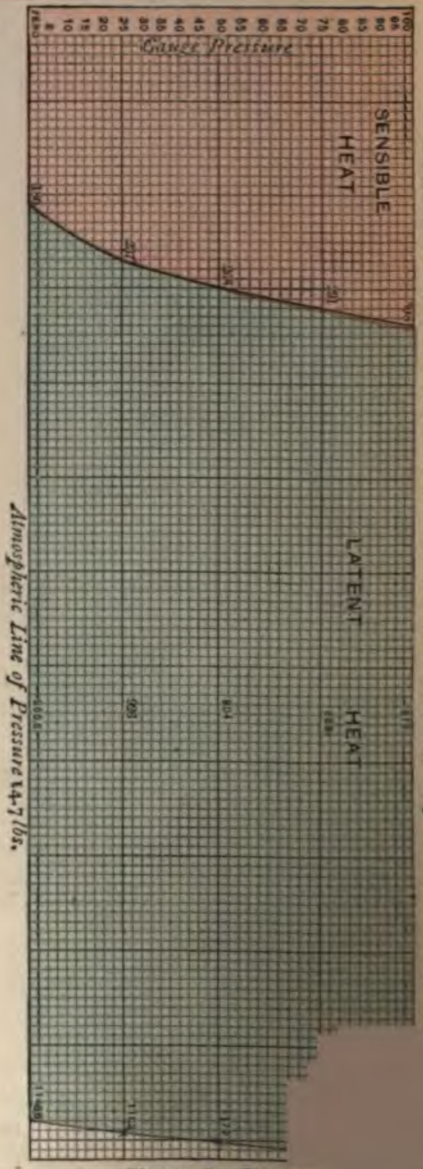

Figure 3—Steam.

Sensible and latent heat of steam shown by Table No. 1

CHAPTER XXIII

WATER APPARATUS, ANCIENT AND MODERN.

"THE origin of employing hot water for diffusing artificial heat appears to be hid in considerable obscurity. It is not improbable that, like many other discoveries, it has been reproduced at different periods. It seems, however, to have been first used in France, by M. Bonnemain, in the year 1777, and was employed by him during several years for hatching chickens by artificial heat.

"The French Revolution, which followed shortly afterwards, put a stop to this, as well as to many other useful and scientific inventions, in that country; and for several years the invention seems to have been entirely dormant; nor, indeed, does it appear to ever have been used by M. Bonnemain except for the purpose above mentioned.

"About the year 1817, the Marquis de Chabannes introduced a similar apparatus into this country for heating a conservatory, and also heating some rooms in a private house by pipes leading from the kitchen boiler. In the following year, he published in London a pamphlet, describing his apparatus and some ingenious modifications of hot-air stoves. The invention appears to have made but very little progress for several years. In 1822 Mr. Bacon, a gentleman of fortune, introduced the use of hot water into his forcing-houses, using for the purpose a single pipe of large diameter, communicating with the boiler; and by giving a slight elevation to the pipe from a horizontal line, he was thus enabled to produce a circulation of the water, the hot water passing along the upper part of the nearly horizontal pipe, and the colder water returning to the boiler along the lower part.

"The circulation in this apparatus was very imperfect; and Mr. Atkinson, an architect, almost immediately afterwards suggested the addition of a second pipe to bring the colder water back to the boiler; and thus at once the apparatus assumed the form that it has ever since retained. By this alteration the apparatus was brought very nearly to the same form as that contrived by M. Bonnemain more than forty years before; the principal difference being that M. Bonnemain used only very small pipes of gun-barrel [illegible] r. Atkinson used pipes of four or five inches in diam[illegible]

"The honor of this invention had been claimed by Mr. Watt prior to the time of Mr. Bonnemain using it in France, but there appear no grounds for supposing that he ever employed it without the intervention of steam as a distributer of heat by circulation in the manner in which it is now used.

"The use of hot water in pipes is an invention of far greater antiquity than the time of either Watt or Bonnemain.

"Seneca has accurately described the mode of heating by water in the Thermæ at Rome, of which Castell has given drawings, and which show that the method of heating the baths by passing water through a coil of pipes which passed through the fire was known and practised previous to the Christian Era. And except that these tubes were of brass, instead of iron, they were precisely similar, both in form and arrangement, to those occasionally used at the present day for a like purpose; the lapse of nineteen centuries having apparently added nothing to our knowledge on this subject."

Since the introduction of the hot-water apparatus for warming buildings in this country, the variations made in its more complicated arrangements appear to have been gradually adopted. Each time that an apparatus has been erected, experimentalists have deviated in some small degree from the model of that which preceded; apparently afraid of venturing on too great a variation, yet requiring, from contingent circumstances, some alteration of its form and application.

This mode of proceeding, though natural, while the principles were not thoroughly understood, has frequently led to both inconvenience and loss, in consequence of the numerous failures to which it has given rise, by unintentional deviations from the true principles. In the present attempt to elucidate the subject, it will, however, be shown that success need not be uncertain, provided only that the laws of physics be justly applied and strictly adhered to.

So numerous have been the failures that have occurred in this method of heating buildings, that nothing but the intrinsic merits of the invention could possibly make it retain its hold on popular favor. Every imaginable kind of mistake has been made in apparatus erected upon this plan. And these mistakes still continue to be made almost as frequently as ever, notwithstanding the large number of buildings in which it has been successfully applied, and which might be consulted for correct information.

Neither the capabilities of this method of warming nor the various useful purposes to which it is applicable are fully appreciated. There are no buildings, however large, to which it cannot be advantageously adapted, nor any that present insurmountable difficulties in its practical application.

WARMING BY WATER CIRCULATION.

The application of water to domestic heating, and to the small and simple circulation made by the florist for greenhouses, is that treated by early writers: Tredgold, 1836, Charles Hood (first edition 1837, last 1879), David Boswell Reid, 1844, and Thos. Box, 1866 to 1880.

Of the older writers on water as a heating agent, none have been as clear, practical, and generally satisfactory as Charles Hood, whose last and fifth edition has been consulted, and will be freely referred to. There is also a late work on warming buildings by hot water.* Of this work it may be explained that in general it is confined to well-known principles of the action and behavior of heated water in pipes and radiators when placed under certain conditions. There are many tables and original diagrams illustrating the text; altogether it is a valuable work of reference and for many details not found in older books.

To those, however, who have not yet availed themselves of the opportunity to add it to their library, we may say that the matter appeared in the serial numbers of the *Sanitary Engineer*,—later the *Building Record*,—under the signature of "*Thermus*," this doubtless being both a convenient and profitable arrangement, Mr. Baldwin (Thermus) being at the same time on the editorial staff of the paper, and thus in a position to ask and answer many questions relating to the subject matter of the articles in question.

Another valuable book, "Steam Heating Problems," was published by the *Sanitary Engineer* in the same way, and thus collects in compact and durable form matter before published and distributed to the readers, but which was not likely to be preserved by them in the more bulky form of a weekly journal.

A third book, also by Mr. Baldwin, "Steam Heating for Buildings; or, Hints to Steam Fitters," 1881, may be mentioned, although it is doubtless in the hands of most steam fitters looking for hints and points on construction by which to enlarge their generally contracted knowledge of *principles* and applications. All of these books refer to and advocate only well-known and sound practice, and may be consulted confidently by those in want of information in the line they treat of. They are often referred to in these pages, and Mr. Baldwin's experiments with steam and water may be found classified in tables 10, 11, and 12.

There are several other books in which water is discussed in connection with the general subject of heating dwellings and greenhouses. They will be referred to later, and are found listed on the schedules of books consulted, so that we will confine our remarks to some other details and conditions not treated extensively by them.

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* *Hot-water Heating and Fitting*, William J. Baldwin, 1889.

While water as a heating agent has long been before the public, both in the United States and Europe, yet its general application has progressed slowly, and seems to remain in the hands of a few individuals and companies, who, having made a study of some one type of work, confine their operations and contracts to that one apparatus. Thus, in this country we may count on the fingers of one hand all those firms that may be cited as successfully doing water heating on any scale of magnitude, and only one of those attempting the larger class of buildings with a water circulation.*

True, within the last two or three years quite a number of people have gone into the business of erecting a simple form of water apparatus, mostly for dwellings, and the use of coils and radiators located in the rooms to be warmed. In these applications, using a small portable form of heater and running the pipes promiscuously through the rooms, a fair degree of success is being reached, and, under the stimulus given the business by a lavish expenditure of time and money by the manufacturers, much interest is being created for water heating in this portable and compact form. In a former chapter on boilers we have illustrated several of these modern devices, and, while calling attention to their good points, have also noted some errors of construction and estimation regarding the power and value of heating surfaces so arranged.

It is a noticeable fact that, while portable house-heating boilers are the latest apparatus of this kind to appear with a water circulation, they do not bring with them any new or modern ideas as to the manufacture of such goods or methods of applying a liquid heat circulation.

Several of the most prominent of the portable heaters are Canadian inventions, and embody what may be termed the English methods of water application, such as may be seen in almost all the apparatus noticed by Hood, and constructed by Garth, of Montreal, and Bennet and White, of Toronto. This may be described as a water apparatus open to the atmosphere and limited in temperature below 212° Fahr. It also includes an extensive divisibility of the heating current by the employment of many supply and return lines to and from the radiating surfaces. See diagrams of piping, page 467.

While the writer does not employ these methods, but rather the reverse of them, it does not follow that he condemns their use, or that there is nothing valuable in such arrangements. Indeed, in many instances, where the intelligence of the people into whose hands such apparatus falls is of the lowest order, all other considerations except those of simplicity and safety should be ignored.

As, however, system or method is in this matter of heat (as in navigation) all important, we may properly glance at the two principal applications or methods of employing a liquid heat agent.

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*Bartlett & Hayward, Baltimore, Md.

There is a third heated and mechanically *forced* circulation. This will be described on pages 429, 430.

The first, oldest, and we may say most common, method of construction and operation comprises a circulation in the boiler, pipes, and radiators of water rising and limited to temperatures *below* 212° Fahr., this being sought or entailed by leaving one part of the apparatus open to the atmosphere by a pipe, generally from the expansion tank, for convenience connecting to the drain. By this simple means any excess of pressure, and thus any excess of heat over the boiling point of water, is thus quickly sent to the sewer; and it is explained to the purchaser that this is his remedy from any over-pressure due to excess of fire in mild weather.

True, this is a remedy, and one usually employed in the tanks of *wind mills;* but in that case the motive power costs nothing, and can very well be disposed of in that simple way. But where the motive power is coal at $6 or $7 per ton, it seems paying dear for a whistle that can well be dispensed with.

The first practical *steam* apparatus that we had in this country, the Gold's heater, 1859, was operated and limited by an open pipe. The first radiator, being of sheet iron and large flat surfaces, would not bear any considerable pressure, and reliable safety valves were not so common then as they are now.

While there are several reasons for operating an open-tank system of water circulation, the main one, now as then, is that the heater and radiator offered with this system have large flat, and thus weak, surfaces, on which even a moderate pressure might operate unfavorably.

In other constructions, where several horizontal sections and joints are held to a seat by short and long bolts, pressure would be an element of danger, at least to the manufacturers, and so they decry it, and advocate a system in which almost any pot or kettle would be safe from pressure and breakage.

Viewing the two elements of water and steam as heating agents, there seems to be no good reason, except the ones above noted, for drawing a line between them in the matter of pressure.

As to safety, one agent, under moderate pressures employed, is as safe as the other. We have heard much about the incompressibility of water and its great power of expansion in a closed vessel. This matter was even illustrated in the *Building Record*, and a drawing was made to show conditions that could not exist in practice if the apparatus were constructed with even as little care as is bestow [illegible] n-heating apparatus; for the latter, without a safety v [illegible] for excess of pressure, would be detected a [illegible] cusable blunder; the same may be said of a [illegible]

THE EXPANSION OF THE WATER.*

The matter of the expansion of the water in the pipes of a liquid circulating apparatus is one of importance, as bearing on the proper construction of the boiler, pipes, and radiators.

It is generally considered by older writers, and formulæ are given for calculating both the expansion and the resulting pressure, provided there were no room or space left for the surplus water to flow into.

The expansion of water, steam, air, or metals is well known, also the means to provide for it, so that no damage results to any of the parts of the apparatus that do not expand. This is given in tables applying to different materials.

Of water we may see that it is regular under regular additions of heat, the whole increase in bulk in passing from 40° to the boiling point 212°, being about one twenty-fifth, or four gallons in each one hundred, or forty gallons in a thousand, and this is doubtless a fair estimate for this rise of 172.°

But this is not the average or working condition of a water heating apparatus, the rise and fall of which does not exceed the 72°, to say nothing of the extra 100°; and we need not even consider the total rise of the water from 40°, since there is no need of beginning a circulation with cold water; fire may be started in a water boiler as soon as the boiler itself is full of water; and while the pipes are filling up, heat will be continually added, until, when all are full, it will then be water at one hundred or more degrees that we are considering, and the extreme expansion referred to is avoided.

Evidently this should be considered under two heads; viz., the conditions and surroundings of a domestic heating apparatus in the dwelling, and that of the larger plant employed in commercial and public buildings.

†A late writer has given the matter of the friction, flow, and expansion of water in a domestic heating apparatus great prominence by devoting much time and space to conditions that might, but that generally do not, attach to any practical heating boiler or fixtures.

He gives tables and diagrams showing the total and possible expansion of water from 40° to 600°, which, although interesting and valuable in themselves, do not seem to have any practical bearing on the issue in question. (That is, the last 300°.)

The whole bearing of the matter is made to revolve around the open and closed tank system as applied to small and domestic heaters, and, but for the well-known ability and standing of the writer, would appear like special pleading in the interest of a certain and limited construction.

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*See diagram No. 21, page 406. †Thermus, *Building Record*.

The writer referred to, further discussing expansion, says:—

"The power to burst vessels or cylinders, however, commences at the atmosphere, and counts therefrom; therefore up to the temperatures of 212° in an open apparatus the walls are not strained by the addition of heat. Beyond this point, however, to secure any given increment of the temperature, we must also have an increment of pressure, and consequently must have either a closed tank in which to compress air or form steam, or be under a head of water equivalent to the pressure we desire. See table of experiments, pages 472, 473.

"*Up to a temperature of three hundred degrees Fahr. the necessary pressure cannot be said to be very dangerous, as with a properly proportioned and operated tank they will not exceed fifty-one pounds to the square inch, as will be seen by table.*"

Here we have the matter in a nutshell, and it certainly relieves the writer from any supposed want of knowledge of the facts, and further shows that the point of danger in closing a water boiler *is very remote at 50° higher temperature than we have any need to consider desirable.*

The above references also call attention to the fact that a head of water acts to give the required pressure and heat above 212°.

In all this matter of an open or closed house-heating plant, it has probably been overlooked that all the bath-boiler arrangements in the country are worked on the closed-tank system, and that only in remote cases, like the (frozen up) apparatus at Milwaukee, has there ever been a dangerous accident.

True, most of the bath boilers are connected directly with the hydrant, which is thus the expansion tank and safety valve required; and, indeed, there is no real reason why the other water-heating boiler, pipes, and radiators should not be connected in the same way, and thus further simplify and cheapen the domestic water-warming plant.

The writer has so connected several small heaters, which worked to perfection. Of course the water should be attached as high up the pipes as possible, so that, in case the hydrant or other regular water supply was cut off, the water in the boiler, pipes, and radiators would not run out. In fact, they would then only be for a time under the open-pipe system.

That the domestic heating apparatus should be of the simplest construction and have every safeguard thrown around it to eliminate danger and guard against accidents, should go without saying; and, if an open pipe from the expansion tank *only* device at the disposal of the constructor, w have it. As we have shown, the ranges of nt pressures) are 200° below the danger l 25° are practically confined to only the la

If any person choose to employ an open pipe to take the place of a safety valve, either because it is cheap or because the plan favors his particular construction, why let him do so, but do not parade the scientific bearing of a plain malconstruction. That the water apparatus should be placed under the same fittings as to *safety and over-pressure* as the low-pressure steam apparatus in the same situation, should go without saying. In many cases plumbers, where setting a bath or range boiler, use both a pressure and a vacuum valve to provide against any possible over-pressure or the reverse of it. It is also a common practice with the writer to use a diaphragm damper regulator with water as with steam, the lever of which is attached to the lever of the safety valve, thus making assurance doubly sure.

As a matter of fact, it is not probable that the conditions of high pressure noted are ever present, certainly not with that class of portable heaters which were had in mind by the writer; since with their limited draught and heating surface, and with the load of cooling surfaces imposed upon them, they rarely ever manage to raise the temperature of the water as high as 212° Fahr., even after hours of excessive firing; their troubles are in the reverse direction, and a blower is the fitting most needed. See pages 292, 293.

Having placed water under all the conditions known to the trade and under some not known to them, I can affirm that I have never seen any excessive or dangerous pressures in a water apparatus, or any additional rise of pressure over what the apparatus has when cold, fifteen to twenty pounds, covering the whole range of small and large apparatus. These will be noted in their regular order.*

Leaving this matter for the present, we will proceed to note that, as the efficiency of both boiler and radiating surfaces are in proportion to the *temperature*, we may see the importance of having an apparatus *not limited to low temperatures when the weather is the coldest and the demand is greatest.* If the temperatures of the radiating surfaces can only be worked between 150° and 212°, the radiating surfaces must be increased to correspond to this condition; and, in the schedule of the manufacturers of this mild water apparatus, we note that they advocate the employment of about one square foot of radiator to warm *thirty cubic feet of space.* (In dwellings with average exposure and conditions.)

On the other hand, with a closed tank system and circulation, the temperatures ranging from 150° to 250°, one foot of water radiator will warm *sixty feet of space* and in the most exposed situations, always supposing that there are proper grate and absorbing boiler surfaces to supply the heat demanded.†

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*Experiments always excepted.

† See Table of Water Heating, at Springfield and at the Pierce Building, pages 441–447.

It is common practice, where there is a general supply or storage tank in the attic of dwellings, to attach the house-heating boiler to it, thus securing a water supply and expansion at the same time.

As a matter of protection, and at the same time to secure the small needed pressure, it is common to put the safety valve on the boiler in the basement, and set the weight for ten, fifteen, or twenty pounds, which the height of the water in the high pipes will indicate; the weight is then wired in that position, and all is safe as far as over-pressure is concerned. The truth is that, with the generality of small house-heating apparatus, that the grate and heating surfaces are so small, compared to the cooling surfaces imposed, that they rarely have any superfluous power to show in either temperatures or pressure.

Passing this, we may note that all these supposed high temperatures and possible pressures are reached only with open damper and no control of the fire.

Most all domestic steam-heating apparatus has some automatic damper worked by the pressure, and there seems no good reason why the water-heating apparatus should not have the same; since, as temperature and pressure always go together, a diaphragm regulator may be connected to the pipes of a water heater, and operate as promptly as when steam furnishes the pressure.

In the examples of water heating to be presented, some of the best heat lines were obtained where the fire was controlled by a thermostat in the rooms, operating, through electric wires, a clock movement, which opened and closed the dampers when the proper heat was present in the rooms above. It is evident, however, that the perfect heat regulator for the control of temperatures in all kinds of furnaces is still a desideratum, and just now the mind of the inventor and speculator is very active in that direction, and will doubtless continue, and ere long produce the desired machine.

As to this matter of an open or closed heating apparatus, it may be remarked that the first low-pressure steam boiler (that of Samuel Gold, 1859) was designed to work with an open pipe, carried to the top of the building, and having a column of water, the weight of which was to determine the pressure, and act the part of a safety valve. In a little time, however, some ingenious person saw that a safety valve in the basement would answer every purpose, besides securing the additional heat due to the temperature so obtained.

An open steam and an open water heating apparatus are really one and the same plan, and those w [illegible] construct and operate them can take their choice; but [illegible] s is limited in its operation, and more crippled in [illegible] m boiler would be under the same conditions.

THE FLOW OF WATER IN THE PIPES.

The flow, friction, and expansion of water in the pipes of a heating apparatus, while of interest to the engineer and student, are not yet reduced to a universal application.

Mr. Hood says: "The calculation of the friction of water passing through pipes is alike complicated and unsatisfactory; though the question has been investigated by some able philosophers and mathematicians, a simple and correct formula is still a desideratum, and it would be almost impossible to determine what would be the resulting velocity in a hot-water apparatus of complicated construction."

Although some difference of opinion has existed as to the real motive power of a heated-water circulation, there is a general agreement among professional engineers and practical men when they are considering a simple open tank and gravity conditions.

Tredgold, however, was not quite clear as to what really did produce the circulation of heated water in pipes; at least, it is notable that he did affirm that the whole power was not to be found in the slight differences of weight between the return and supply columns. Hood also asserted that the laws of hydraulics for the flow of cold liquids do not fully apply to hot circulation in an open or closed apparatus.

It may be noticed, also, that, while he held to the general power by gravity referred to, he also mentions the increased power of liquids to flow when their *fluency* is increased by heat.

He quotes Dr. Ure as saying: "Water, by having its temperature raised from 60° to 164°, has its velocity increased about one sixth. These results are wholly independent of any effect from alterations of pressure, but appear to arise from the particles of the fluid possessing less adhesiveness among themselves by the increased temperatures."

Hood, while holding that the power to move a liquid circulation was practically gravity or the weight of a cold column pressing upon the warmer and lighter one, was yet clear as to other influences; and he pointed out and illustrated the increased power to be derived from arranging the flow and return pipes of an apparatus in *vertical* rather than in horizontal lines, and this without any reference to an open or closed apparatus. Yet he evidently had the former in mind in all his treatment of the subject, especially as he says "the temperature of the water in the pipes can never rise higher than 212°, as, if it were suffered to do so, steam would form, and stop the circulation."

The effect of friction in reducing the velocity of the water or in determining the ultimate velocity that the flow will attain, may be seen to be a very complicated subject.

It is, however, possible to obtain a general view of the subject, and there are principles whose application may be of assistance in designing water apparatus.

That Mr. Hood and Mr. Baldwin were both treating of low-temperature apparatus, is understood; but it was reserved for the latter to take the peculiar ground that only an apparatus open to the atmosphere and limited to temperatures below 212° was either safe or desirable.

That this is the ancient and common method of open-tank construction and operation, we will admit; that it is common to most all portable and greenhouse apparatus, and to the simpler constructions which in the past have been put into dwellings.

That there is any more danger in closing a properly constructed water heater than a steam one, is not made clear by the array of conditions that are not liable to occur in either apparatus.

An expansion tank of proper size being one of the main requisites of all water apparatus (except the bath boiler), and a safety valve being also applied to the heater, the danger of over-pressure at the temperatures of 230° to 250° is very remote. That the domestic apparatus has or ever could be got to the excessive temperatures stated, is not probable.

Generally these *heaters* with, say, two feet of grate surface and perhaps forty feet of heat-absorbing surfaces, are piped to anywhere from six to eight hundred square feet of cooling surfaces in the shape of coils and radiators; and in the season when the outside temperature is low, they can rarely be got to as high a temperature as 212°, let alone any higher ones; and the great expansion and pressure reached at temperatures of 300°, 400°, and 600° could never be laid at their doors.

That it is possible to shut up either a water or steam house-heating boiler, and then fire it to a dangerous and bursting point, is perhaps true, and we believe this was done in the cases noted at Chapinville and Eagle Bridge; had, however, these not been *wrought iron and shell boilers*, nothing but a rupture of the weakest part would have resulted; as the boiler was wrought iron and *loaded*, the usual results of such experiments were secured.*

It is not a matter of heat alone that is involved in a closed apparatus, but of circulation and general efficiency, although the method of piping adopted by the writer may be employed on an open as well as a closed apparatus, *provided the expansion tank is connected to the bottom of the boiler.*

Even an overflow pipe may be employed, if this simple device has such a hold on the engineer that he cannot get away from it, or select boiler and radiators that are not themselves weak somewhere in their upper or lower works.

The theoretical calculations brought to bear upon this subject by late writers, while doubtless correct in the main, are liable to require adjustment if the conditions are changed or are not those predic

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* See page 225 on unsafe boilers.

The following explanation of the principles of the motion of a hot-water circulation follows closely that given by Charles Hood, F. R. S., Box, Schuman, Tomlinson, and most others who have written on the subject, in ascribing the source of motion in the apparatus to the difference of density between the opposite columns of hot and cold water. The theory as presented in older treatises for pipe alone, has been enlarged here so as to include the more modern forms of apparatus where radiators take the place of long circuits of pipes.

The cause of the flow of the water as thus explained is easily understood and free from complexity. The only point where there is any opportunity for a difference of opinion is in respect to the expansion of the water, and the effect of the small increase in volume, due to heat, in accelerating the flow or in producing motion. This has been considered.

Much has been written on the *theoretical* flow of both steam and water in the pipes of heating apparatus; and, while this is of interest to the student, and would be necessary in certain cases of magnitude, such as the supplying of heat from central stations, I doubt if any domestic or commercial heating plant has ever been *calculated, constructed, or operated from data so obtained.*

If there has, in all probability some practical mechanic in the line of pipe fitting had a chance to try his hand at the other part of the problem; viz., to *make it work* by supplying the missing links in the chain of causation and the rule of three.

The writer would not be understood as undervaluing theoretical calculations. Indeed, they are essential; we must have a theory before we can have a practice. What, however, is of the most importance is a *correct theory* and a *practical practice.*

Mr. Baldwin in his late work has given much time and space (over the half of his whole book) to the flow and friction of water in the pipes of a heating apparatus. That these had reference to the *open* system and horizontal circulation, limits somewhat their application; but his clearness in presenting the data so derived, makes it easy to understand and compare them with other formulas and conditions.

The difficulty with many books that have been written on either steam or water heating is that they are not often on the level of those that require *practical* information. If a book is all theory, it can only reach a man who is examining general principles—a student or engineer in some branch of heat engineering. If, on the other hand, it treats only on the practical application of some principle already understood, it falls flat for the want of novelty and utility, or rather information of the character that the engineer, architect, or heating contractor can put into practical use.

That nearly all writers considering circulation have done so mainly by applying the laws of hydraulics of the movements of *cold fluids* in pipes to those of a heated circulation, seems singular. That the friction of cold water in pipes may be arrived at by Prony's, Box's, or Ellis's formulæ, is doubtless true; but there are so many other agencies at work in a *heating apparatus*, retarding or increasing the circulation, that it requires other data than those referred to, even to approximate the final result.

While the primary motive power may be traced to the difference in weight of two columns of water, and then again transposed into a difference in head, there are many other factors that must be taken into account, such as the area and diameters of the pipes, the angles and turns imposed, the vertical and horizontal distances to and from the boiler, *and the kind of boiler employed.*

It is apparent that, if the main body of the surface is on a lower level, say "indirect" surface in the basement, the addition of a small amount of radiator at a higher level will not materially increase the circulation, the power being in proportion to the *amount of the surface and its height above where the heat is applied.**

The circulation of the water in any apparatus, with its consequent efficiency, depends mainly on the following conditions: —

1ST. THE HEIGHT OF THE COOLING ABOVE THE HEATING SURFACES. Just as in a chimney height is an element of power in increasing the draught, in a hot-water apparatus increased height results in a more rapid circulation. If a stone is dropped to the ground, it acquires greater velocity in falling from a high elevation; and similarly the excess of weight in the cooler water, descending from the top to the base of the apparatus, acquires a greater velocity if the fall is from the second story than if it is from the first story of the house. Where the various radiators are located at different heights, as is generally the case, the power will be determined by the mean height of the radiating surface above the lowest portions of the heating surface of the boiler.

2D. THE RAPIDITY OF COOLING is another factor that determines the power of the circulation. As the water cools more rapidly, the difference of weight between different parts of the apparatus is increased, and the whole tends to equalize, and attain a more stable equilibrium by motion. This method of increasing the circulation can be employed only to a limited extent with the open-tank, low-pressure system; since the temperatures, being already low, do not admit of much further decrease, and still maintain this efficiency.

3D. THE POWER OF ANY APPARATUS TO [illegible] AND OVER-COME THE OBSTRUCTION OF FRICTION IS I[illegible] TEMPERATURE OF THE WATER SUPPLIED F[illegible]

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* See article on vertical boilers, [illegible]

This is due to two independent causes: *First*, when the temperature of the water in the radiators is high, that of the metal is correspondingly increased. Thus more heat will be given out by the radiator in a given time, the rapidity of the cooling being proportional to the difference between the temperature of the radiator and that of the air and other surrounding objects.

Hence the difference of weight, due to the cooling, which is the cause of motion, is being constantly augmented.

A *second* important source of power is due to the fact that, for a given difference of temperature, water expands more as it becomes heated. The gain in weight of a cubic foot of water for different temperatures is as follows: —

7.2 ounces, when cooled 30° from 130°.
9.8 " " " 30° " 180°.
11.7 " " " 30° " 230°.

It will be seen that for *the same difference of temperature*, the relative difference of weights between the water before and after cooling is 62 per cent greater at 230° over water at 132°, and 20 per cent greater than for water at 180°; and the power to circulate is better at the higher temperatures by the same percentage due to this cause alone.

4TH. WHATEVER DECREASES THE FRICTION, WITHOUT AT THE SAME TIME REDUCING THE EFFICIENCY OF THE RADIATING SURFACES, STIMULATES THE CIRCULATION.

That a body of heated water in any vessel connected by pipes to a colder one is in condition to move and circulate, is clear; so that a body or tank of water heated by steam would obey the same laws of gravity and circulate reasonable distances, the part that had been cooled furnishing the motive power for the return circulation. This application is sometimes seen where several greenhouses are heated by an independent water circulation, the heat for which is furnished by a central steam boiler.

The briefest examination will, however, show that it is *the vertical height of the heated column in the boiler and pipes that determines whatever of power is secured in any case;* therefore it is by the *height of the boiler* that we obtain our first factor of power.

Referring to the boiler, we have seen that about every possible variety of form and construction has been found available to produce a water circulation; but little attention has been given to the secondary matter of comparative power and to the more vital one of vertical height as affecting the result, also to the importance of position and amount of water to be acted upon by the heat.

THE POWER RESIDES IN THE BOILER.

Before leaving this interesting question of the cause of motion in a hot-water circulating apparatus, we may note as a singular fact that in all the treatment that the subject has received at the hands of writers, only one has referred to the first and original source of heat and power; viz., that derived from the *boiler*, where the heat is first absorbed. Clearly any power in heated water to move must be credited *first to the source of motion, which is heat; second to position, while being heated*, and that which the liquid takes immediately afterwards.

A given weight of any substance has a power due to the height from which it may descend. Thus water in the hills is a source of power due to its elevation above the sea; but, once *below the dam*, it will no longer turn the wheel, and we have the significant line,—

> "The mill will never grind again with the water that is past."

A boiler with a fire in or under it is the spring from which the water is flowed to such elevation as the pipes will permit; and every foot of vertical height in and around the fire is a direct and positive source of power to reach any desired elevation, and the potency due to such elevated position. If there is but little vertical height in the boiler and piping, there will be but little power secured to perform work and overcome friction.

Thus when heat is applied below the horizontal shell boiler, the water has but little depth above the fire, and, being *en masse*, is mainly heated by *convection*, currents being set up internally; the portion of water over or nearest the fire imparting heat to other colder layers situated at a distance from the fire. Thus a portion of the power imparted to the water nearest the fire is expended in warming and putting in motion the large body of water remote from the source of heat; and, if no vertical height is given the flow, the power available for carrying on an extended circulation is very slight at the start, and is continually lost by friction in both supply and return lines.

Besides this unfavorable condition for the reception of heat and flow of the heated water, we have also lost power to flow by a loss of say one half of the vertical height *possible with an upright instead of a horizontal form of boiler.*

That the amount or bulk of water treated or handled in a liquid circulation has much to do with the result, is clear, and that it is possible to carry this to a point detrimental to either efficiency or economy.

The liquid for a heat circulation should be placed in a vertical position, both as regards the boiler, pipes, a [illegible] *s in these lines the least friction and greatest efficiency will* [illegible] hat the water should be subdivided and the heat a [illegible] t of the hot leg of the loop. See article on cast [illegible] s, pages 291–296.

That this divided and vertical position of the water in a liquid-heating boiler is of the first importance, will be seen as we examine further into the primary motive power of heated circulations. This part of our subject is not left to theory or conjecture, having been made the object of much experiment prior to final construction, some of the results of which have been illustrated and tabled.

The value of subdivision of the surfaces in all *condensing* operations is well known, and we now see why it should extend to machines for absorbing heat. This construction is found in nearly all our fire engines, which are of the vertical class, and with water spaces of the smallest dimensions, the drop-fire tubes being commonly about one inch in diameter. The locomotive, having also an internally fired furnace and many tubes, reduces the water space, and thus subdivides the heat-absorbing surfaces.

We thus arrive at what should be our first condition and care in attempting any water or liquid circulation; viz., its position and arrangement in the boiler and heater. As we have already clearly seen that all the motive power in an apparatus is derived from *vertical columns* of heated and cooled fluids, so we may see that not only does this condition extend to the boiler, but that it in reality begins there, as it is in the basement that the greatest difference of temperatures between various columns of the supply and the return water is found; and, therefore, it is at the *boiler* that we must look for our *first and main source of power.*

As each pair of vertical pipes forming a loop may be taken and figured separately for their available power, so each separate vertical column of water within a boiler is a source of power, and the total power of a water-flowing boiler may approximately be estimated by *the number of vertically heated columns acting conjointly on the main flow from such apparatus.*

In all electric machines, such as *dynamos* and *motors*, we see that the power to flow the electric current is largely determined by the number and size of the several wires employed; in other words, how the machine is *wound*. So in boilers designed to flow water, we shall find that it is not the mass of heating surface and quantity of water employed, *but the number and position of the several lines receiving and parting with heat* (*which is also transferred into motion*).

With these primary elements properly arranged and controlled, almost any desired power to flow water may be obtained; this will be further taken up, and will be seen in all the illustrations presented.

See cuts and sections of the buildings at Springfield, Mass., and conditions at the Pierce Building, Boston, Mass., pages 439, 443.

Having seen that the greatest power to circulate in the pipes is obtained from vertical lines, as little subdivided as possible, we may now state that the reverse of this holds good when we come to the boiler, and find that the worst possible condition in which to heat water for circulation is when placed *en masse, and fire applied to only a limited part of the water to be warmed*, as, for instance, in the horizontal tubular boiler; and this may be further stated to consist both in the position and the quantity of the water acted on by the fire.

The horizontal shell boiler for average size — say twenty-four horse-power, or three hundred and sixty-six square feet of surface — presents a solid body of water three feet deep by ten feet long, or about three hundred and twenty-five gallons of water would then be acted upon by a limited amount of heating surface,— say one half of the shell, or fifty feet,— the rest of the shell and tubes, three hundred square feet, being only indirect or remote absorbing surfaces. Thus the main work is done by 20 per cent of the total surfaces; and most of the work would, of necessity, be done by "convection"; that is, by heating one portion of the water by another, and, if the body is large, requiring time and space in which to set up this *internal and altogether unnecessary circulation.*

This term "convection" is imperfectly understood by many persons, when treating of the heating of liquids that are not *en masse.*

A late circular by a manufacturer * gives cuts, and attempts to explain how water is always heated by convection, and that their particular construction is valuable because this operation has been carefully studied and incorporated in latest designs for heaters. The real facts are that, by the very nature of the construction cited, "convection" is possible only to a very limited degree, and because of that, their boiler is valuable as a *direct* water heater. No large body of water is heated by another. Certainly both propositions will not hold good at the same time, and the more valuable one is lost sight of, to bring in a condition neither desirable nor indeed present.

Another vertical heater manufacturer, while making and describing a similar heater, claims to have escaped the heating of one portion of water by another, by causing their entire water to *flow in a direct line successively through the several sections*, "passing the water seven times over a fire-heated surface." This is the reverse of convection.

Certainly but for some increased efficiency secured by this class of vertical and portable heaters, they could not make their surfaces carry from three to four times the load of radiators scheduled for horizontal tubular and other boilers. Clearly, then, as heating by convection and by direct contact is [illegible] operation between these different movers of [illegible] opine that the direct-heater people will fi[illegible]ndition of the horizontal shell boiler.

The matter of the transfer of heat by *convection* currents set up in large bodies of water having a local and limited amount of heat, while of philosophical interest, or as studies for children, has no practical bearing on the construction and operation of a boiler or a heating apparatus that in no way resembles the models and conditions referred to.

We may state it broadly that the heating of a large body of water by a limited fire surface (by convection) is where the horizontal tubular boiler *fails both in economy and power*, and that the reverse of this condition is seen in the vertical and sectional heaters of which the *Gurney*, *Perfect*, and *Spence* are examples. The principle of heating water in small vertical columns is further seen in the ***Mills*** and ***Mercer*** boilers. (See chapter on Vertical Water Heater, pages 289–300.)

Thus we may repeat that the worst possible form in which to heat water for a fluid circulation is in bulk, or in a horizontal position, and the best form in which to place it is in a vertical and sectional boiler, regardless of the materials, or who makes, sets, or sells either kind.

I am aware that one or two firms employ the horizontal tubular boilers for water circulation successfully, but the whole method, conditions, and surroundings must be adapted to it.

To overcome the want of height or head in basements, it is customary to sink the boiler in a pit below the basement floor, so as to obtain the required fall or difference between the supply and return lines.

The sinking of the boiler is a clumsy and expensive device to compensate for lack of headroom, since much better results may be obtained by elevating the supply; that is, leaving the boiler at the natural level and flowing all the water to a point above the level of the floor where required. If there are no high radiators, the expansion tank should be arranged to take the entire contents of a single flow pipe, when one or more secondary supplies may be dropped down, and carried where desired.

This kind of a circulation on a large scale is illustrated in plate No. 43, being a section of the county buildings at Springfield. We have before referred to what engineers are pleased to call the "phenomenal" water apparatus of any country; since all the adverse conditions that could be brought to bear on apparatus are here met and overcome, *while one foot of radiator warms ninety feet of space, with excessive wall and glass exposures.**

It should be seen that any plan that holds up the supply temperature and reduces the return, quickens circulation, also that the greater amount of heating surface which can be carried on any one line accomplishes the same thing.

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*See cuts and table No. 17.

Returning to sectional boilers and heaters, we may see that, instead of a large body of water lying *en masse* to be heated by convection, there is a much smaller body, less than one third, subdivided into small columns or spaces, on which the heat acts directly, and thus causes immediate movement of the water away from the heated plate; and circulation ensues in the flow pipes instead of inside another body of water, which must continue until heat enough is imparted to the whole mass to cause it to move slowly out of the flow pipe.

* It will be seen, by reference to the tests with water apparatus at the Pierce Building, that within thirteen minutes after heat was applied to the boiler the general circulation commenced; the apparatus in this case containing over two thousand gallons of water.

This quickness of action was doubtless due to the fact that the heated water was free to rise immediately to the top of the building (seven stories); thus the temperatures in the boiler were such as to absorb the greatest amount of heat from the fuel. The larger the apparatus the longer time in general required to start the circulation.

There is a further source of power to move and carry on a liquid circulation in a boiler and heater, lost sight of by the advocates of an open-tank system. While they all agree that the power is proportional to the temperature, to secure an open-pipe system, they must lose the source of power when nearing the boiling point, lest steam should form, and, as Mr. Hood says, "stop the circulation," or, as we may say, lest they send the steam out into the building and the surplus hot water to the drain, through the "innocent overflow" pipe provided to relieve the boiler of any pressure and so any reserve power.

On the other hand, in a closed apparatus having vertical rising mains, temperatures above 212° not only do not impede circulation, but quicken it. Even if steam forms in the boiler and in the rising supply main, no harm will be done or trouble ensue; *the presence of steam only further expands and lightens the flow, and thus increases the circulation, at the same time increasing the available heat.*

The effect of this increase of velocity in the flow is seen at once in the sizes of pipe required to carry a given amount of heat, which is an important factor in determining the first cost of a water apparatus; this is referred to elsewhere.

The sizes of pipes in use and required for the two methods are compared in diagram No. 29, and further illustrated in the sketches of piping for public buildings, and particularly in the report of Colonel Greene on the heating of the Pierce Building. See pages 440, 441.

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* Diagram of circulation, page 437.

HEAT—TOTAL AND AVAILABLE.

The total heat in the water is the gross amount absorbed in heating the water, when cold, to its maximum temperature in the boiler. The amount will vary slightly as the water to be heated is a few degrees warmer or colder within the limits of 32° to 60° Fahr.

It is apparent that the total heat of any apparatus is seldom available. The fraction of heat that is communicated to the air, and maintains the temperatures of the rooms, is represented by the fall in temperature of the water in the course of its circuit, or the difference between the temperature of the flow and the return. The remaining portion of the total heat — which is represented by the difference between the temperature of the return water, after having been employed in the radiators and the pipes, and that of the same water, when cold, before any heat has been applied in the boiler — remains in the water, and continues to circulate, and is only imparted when, from any cause, heat is let down in the furnace, and the whole apparatus cools.

In the "open-tank" system, as employed in domestic heating, there is room for but slight reduction of temperatures, without sacrificing the efficiency of the surface. Hood states that 20° exceeds the difference between the temperature of the supply and return water that usually occurs in practice; also Mr. Baldwin, in estimating the sizes of main pipes and risers, considers a minimum cooling of 10° and a maximum of 15°. Under these conditions only *one ninth to one eighteenth* of the *total* heat in the water is realized.

In the closed apparatus, where the flow pipe may be as high as 230° or 240°, the water may be cooled from 60° to 80°, and still have a mean temperature of 200° in the radiators and the boiler, as high as with the open system under the most favorable conditions. Thus three to four times as much of the heat of the current is utilized, or about *one third of the total heat of the water.*

The advantages thus secured by a closed apparatus are as follows: —

1st. With the same sizes of pipes, from two to three times the radiating surface may be supplied with heat at the same mean temperatures, 200°, as in the open-tank water system.

2d. Where there is no call for increasing the number or size of the radiators, the same surface may be served with pipes of one half to one third the area.

3d. With equal amounts of radiating surface, the efficiency due to temperature may be increased one third over the maximum duty possible with the open water apparatus.

4th. The closed system allows of the same range of temperatures for mild weather, the circulation continuing to lower temperatures of the flow.

See diagram No. 22, Water Circulation, page 437.

THE BOSTON HOT-WATER SYSTEM FOR THE DISTRIBUTION OF HEAT AND POWER.*

The distribution of heat and power has been accomplished on different scales in a number of cities in this country, and successfully, where due precaution has been taken against the liabilities to which they are exposed.

More recently a system for distributing heat and power from a central station by means of *water* circulated through the pipes and mains at a high temperature is receiving marked attention from the fact, as a foundation principle, that one cubic foot of water will contain many times as many heat units as a cubic foot of steam. It is therefore claimed to be more economical to circulate water at high temperature (about 400° Fahr.) and consequent pressure, as a vehicle for heat. (See table No. 14, page 407.)

†"The water is circulated from a central station where a number of boilers are located. From the boilers proceeds a pipe to a pump. This pipe is attached to the suction end of the pump, and consequently the action of the pump withdraws the water from the boiler. From the discharge end of the pump a pipe extends through the streets, and, returning to the central station, re-enters the boiler. As soon as the pump is set in operation, the water flows out of the boiler by the suction pipe, and is forced round through the streets *through a line of piping, forming a loop*, and back again into the boiler by the pump. If during its passage no water is taken from the main, every stroke of the pump withdraws from the boiler and returns to the receiving tank in the boiler-house an equal quantity of water. In reality the office of the pump is simply to sustain a continuous circulation through the hot-water main, or *loop*, as explained.

"Directly beneath the hot-water main there is another pipe, which in the station terminates in a tank. This second main collects the water as fast as it is used and cooled, and returns it to the station, from which function it derives the name of the return main. As the return main empties into the tank, all the water which is cooled and carried back to the station is delivered into this tank, from which a second pump draws the water and forces it back into the boiler, to again receive a fresh quantity of heat and be ready for another journey through the supply main.

"From point to point along [illegible] small pipes extend to the curb stone and terminate in [illegible] The pipe in the service box is so arranged as to enable [illegible] three houses.

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* This is known as the Prall system [illegible] June, 1888.

"The supply pipe is made of "extra heavy" pipe which will resist twelve thousand pounds per square inch; every piece which has been used has been tested to four thousand pounds per square inch, and the whole main tested to fifteen hundred pounds per square inch as fast as laid.

"It is expected to deliver water to customers at a temperature of 400° Fahr., which corresponds to two hundred and thirty-five pounds pressure above the atmosphere, from which will be seen the necessity of strong pipes and fittings.

"Where steam is to be used for power or heating, the water is introduced into a device called a converter. This contrivance may be briefly described as a steam dome. The end of the copper pipe as it comes from the street is attached to a reducing valve, which admits the water into the larger receptacle at a reduced pressure, and part of the water is thereby permitted to take up the superfluous heat and expand or "flash" into steam. The converter is supplied with a safety valve for carrying off any excessive pressure of water or steam due to failure of the reducing valve or discharge trap.

"This system was put into operation in Boston about the middle of December, 1887. The pipe line, after being tested, was thoroughly washed, and the main was then connected with a battery of two hundred horse-power boilers, under which a slow fire was started so as to gradually heat the water in the boilers.

"A steady circulation was maintained throughout the system for ten days. At that time the temperature in the main was raised about 380°. The whole line was carefully watched to ascertain whether leakage developed, and to observe the operation of the expansion joints. No trouble of any kind was experienced, the main under heat being found fully as tight as under cold-water pressure. After thoroughly testing the mains, connections were made for customers, one after another, and at the present time (June, 1888) the company is heating about twenty-five large buildings and supplying steam to a number of engines.

NOTE.—While there is not now any question as to the possibility of sending heat and power over a large territory, using a highly heated liquid as the medium, it has always been a question with engineers and practical men whether such a distribution at the high temperature and pressure required, could be made a *financial success.* This appears to have been the rock upon which this enterprise foundered, as at that date, January 1, 1889, the company suspended operations, as they say, "to examine into the lately discovered corrosion of their carefully tested lines of wrought-iron pipe." At this writing, April 1, 1890, they have not resumed work nor given any intimations of doing so.

In the following plate are seen the boiler, pipes, and radiators as employed in the Mills overhead and single pipe *steam and water system.*

The boiler, A, of vertical construction, is placed in any convenient location, from which a single flow pipe, B, is carried to the highest point of the supply, or above the highest radiators, from which main, horizontal lines, C C, convey the heated element to the sides of the building, where vertical drop lines, D, pass down through the several stories, where they join a common return line entering the boiler.

The radiators, 1, 2, 3, 4, 5, 6, 7, 8, and 9, are attached to these drop or return lines; if water is the heat agent, the radiators are connected top and bottom, as shown (number 6); if steam is the agent, the radiators require but one connection, which is at the bottom (figures 2, 3, and 7); the circular radiator around the column is rightly connected for either steam or water, and the same may be said of the indirect stack No. 9. This is the whole matter of piping in a nutshell.

The main pipe is shown passing up a ventilating flue, but may be run anywhere, and at distances from the boiler before ascending to the top of the building. The expansion tank is also shown as located in the attic, but it might be located anywhere on the fourth floor, or high enough to take the air from the radiators and from the lines C C.

It will be noticed that the distinguishing features of the piping are,—

1st. That the heating agent is flowed, for all vertical work, to a point *above the radiators, which are then connected to the return lines.*

2d. The down line then becomes *both the supply and return* for each separate line of radiation, controlled by a single valve at the bottom or top of the radiator.

3d. That in this arrangement all air is immediately expelled from both pipes and radiators, which will always keep free.

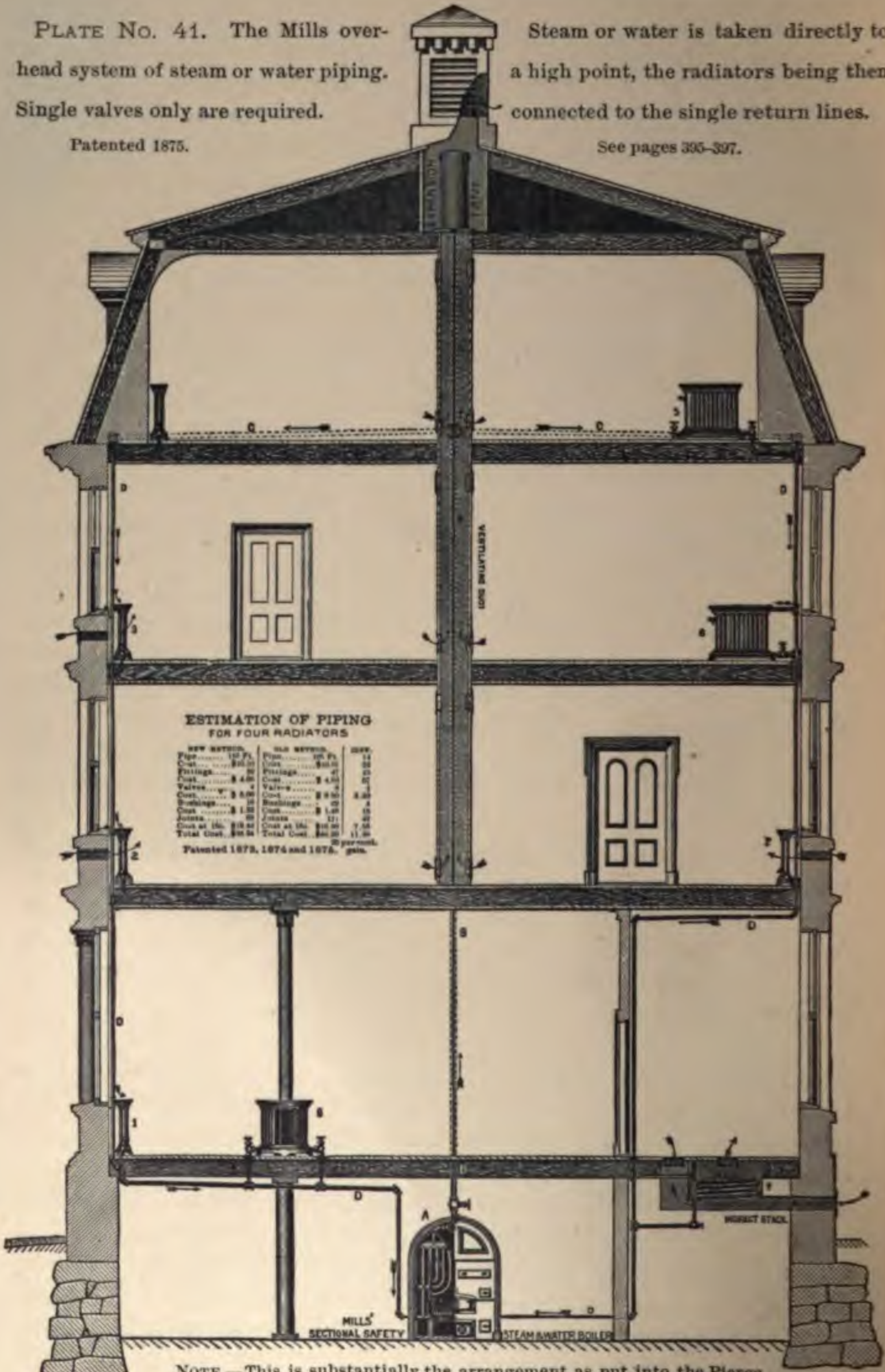
4th. Sizes of pipe that are large enough for steam heating are ample for water. Indeed, they are excessive; for vertical pipes will carry 30 per cent more heat to and from radiators than horizontal ones. This will be further considered and illustrated by cases in practice.

The estimation of the cost of the two methods (centre of plate) is shown for each four radiators, and supposing that we run a supply line from the basement for the four stories, whereas one vertical supply line will serve a whole building, so that the estimate of 25 per cent gain is below the saving effected by this method.

In the largest buildings, it is often advisable to run two rising flow lines, thus dividing the building into two sections or divisions. The Pierce Building is so divided (see table No. 16); heating surfaces, 5,458 square feet; two rising lines, 5 inches diam[illegible] the water flows out and returns to the boiler through [illegible]s only one boiler is in use at one time.

PLATE No. 41. The Mills overhead system of steam or water piping. Single valves only are required.
Patented 1875.

Steam or water is taken directly to a high point, the radiators being then connected to the single return lines.
See pages 395–397.



NOTE.—This is substantially the arrangement as put into the Pierce Building, for water circulation, Boston, Mass., 1889. Pages 434–441.
For conditions of radiator under this piping, see Chapter XXV.

CHAPTER XXIV

WATER CONSTRUCTIONS AND OPERATION.

MILLS SYSTEM, OVERHEAD SUPPLY.*

THE author, while bringing his application of water to the notice of his readers, does not claim entire originality for the single idea of flowing water to a high point and supplying it downward to coils, as a crude application of such construction is seen in the early Perkins apparatus, 1830. Charles Hood also referred to this system, and pointed out some more rational and practical applications of it. His treatment of the whole subject of liquid circulation, while the best and clearest of any, generally referred to an *open-tank and pipe system*, and to double pipe and connection to coils and radiators. He was, however, well informed as to other conditions, and the advantages to be derived from elevation of the pipe, and higher temperatures to be obtained in a water apparatus, closed and under pressure.

The treatment by later writers of the conditions of a closed apparatus proceeded evidently on the assumption that the boiler and pipes were to be nearly filled with water at 40°, and then heated to extreme temperatures, and all this without a properly proportioned expansion tank or safety valve, to relieve the pressure thus created.

That the early Perkins system of heating water to high temperatures and confining it in the pipes with but limited room for expansion, gave rise to much of the literature on the subject of a closed apparatus, is apparent from a perusal of the early and late writers; while but few of them mention the fact that the Perkins apparatus, crude as it was, had an extensive run and use both in the United States and England, it being introduced in this country by Joseph Nason and his partner, Mr. J. J. Walworth, in the years 1840 to 1850. See pages 391, 392.

Perhaps nothing connected with this overhead piping will be harder to understand than this flow of the *water* in single pipes to supply several radiators in the same line, without affecting unfavorably the last or lowest radiators. As the following description of the actual construction at the Pierce Building touches nearly all points, we do not follow this detail further, except to refer to diagram No. 22, which shows the main facts of this remarkable circulation for the whole month of December, 1888. See page 437.

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*See pages 431, 432.

DESCRIPTION OF THE HEATING APPARATUS AT THE PIERCE BUILDING, COPLEY SQUARE, BOSTON.*

This is a building of 551,000 cubic feet of space, consisting of *seven stories, sixty-three rooms, with halls* and other spaces; the first story, 170,000 feet, being on a steam line from the power boiler, leaving 381,000 cubic feet on the water circulation.

Boiler plant consists of three seventy horse-power Mills sectional boilers No. 6. One of these furnishes steam of eighty pounds pressure to the duplex pump for the two elevators and to a forty-two horse-power Armington and Simms engine, which operates the dynamo for the Edison system of electric lighting. One of the other boilers carries the water circulation, while the third is a spare, and may be used for furnishing steam for power or heat for the water, all the boilers being interchangeable for either service.

The piping for the water circulation is connected to all the three boilers by a six-inch cross line in front, from either end of which a vertical rising-main, five inches, is carried directly up to the sixth floor, where it is reduced, and smaller lines encircle the building.

Generally from the sides of this line, as at D (to provide for expansion), the fifteen or more supply and return lines are taken, passing down the outer wall to the basement, where they are gathered into two main branches, and enter the *absorber* at the rear of the boiler.

On these down lines the radiators are attached by two connections, as shown on the section of building, plate No. 41, page 432. It is thus seen that the cooling surfaces are attached only to the *return lines*,— such lines being both supply and return, feeding the radiator, and receiving the water that has passed through them into the same pipe. This matter is fully illustrated in table No. 15, where there are some further references to the facts of circulation and surrender of heat under this simple yet certain condition.

The seventh story consists, as shown, of but three rooms and hall (which is listed with the sixth floor). This floor is supplied by a rising line from the floor below, on the head of which is the expansion tank for this front section; the back section having its own tank located above all the pipes, but lower than the front tank. This second tank is laid horizontally; has but one inlet, which is at the bottom; and is thus air chamber and tank combined. The front tank is 30 x 60 inches, or 182 gallons, two thirds of which is available for expansion and swell of the water. The rear tank is 20 x 72 inches, or 98 gallons, and one half is available for increase of volume, before much pressure would be added to that ordinarily found in the pipes.

Returning to our piping and to plate 41, page 432, it will be seen that the scheme is resolved into:—

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* See table 16, which is a schedule of the rooms, walls, and glass.

1st. One or more vertical boilers, with one or more vertical rising flow lines from boiler to the attic, or the highest point of the general distribution.

2d. A general horizontal distributing line encircling the building, on the upper floor, and a general return gathering line on or below the lower floor, a final branch from which enters the lowest part of the boiler.

3d. Intermediate between the general supply distribution above and the general return line below, are run as many vertical connecting supply lines as are required to serve all the radiators that may be located on these vertical supply and return lines.

4th. That all the heating surface is attached or connected only to the *return lines*, which is the exact reverse of all other methods, and may be taken as the distinguishing feature of this system of piping.

The compound radiator lines are, as seen (table 15, cut No. 23), both the supply of the several radiators and their return, there being no separate system of return and supply lines to each radiator.

Thus it will be seen that the entire piping, vertical and horizontal, on the application of heat, goes into *immediate, positive, and rapid circulation*, having no reference to the radiators, except that, when they are opened up and begin their work, they increase the circulation, and continue to do so in proportion to the amount of water cooled by them, which adds *weight and power* to the return line.

The work possible to any water radiator with any system of piping is known (table No. 10), also that it cannot be increased by any number of pipes beyond the pounds of water that such heating surface will cool per hour, a certain number of degrees.[*]

In the Pierce Building, the return water is not passed directly into the boiler, but into a reheater or absorber, lying horizontally just back of the boiler, and into which is discharged the exhaust steam from the duplex pump working the two elevators, and also the steam from the forty horse-power engine driving the dynamo for electric lighting. The heater is twelve feet long, twenty-four inches diameter inside, and filled with one hundred copper tubes; the exhaust steam passes through the tubes, while the water returning from the radiators flows around these, absorbing a large amount of waste heat.

This is rendered practicable only by the system of piping employed, as ordinarily it would not be possible to make the circulation effective if the *return* water were heated as well as the supply; since, as we have already seen, the power of any gravity water circulation is determined by the *height multiplied by the difference of* [illegible] *between the warm and cold columns.*

---

[*] See diagram of pi[illegible]

The following diagram, No. 22, is the record of temperatures of the water and air at the Pierce Building, taken every day, for the outside air and water, during the month of December, 1888, by the engineer in charge, Mr. Johnson.

The upper line of the diagram shows the mean temperature of the air in the rooms, ranging from 70° to 75°.

The line next below this indicates the state of the thermometer hung outside the building, the temperatures as seen ranging from 5° to 60° above zero.

The two lines in the lower part of the diagram are for the temperatures of the water at the boiler, the upper one being taken by a thermometer placed in the supply main pipe and the lower one in the return pipe, after it had been cooled by passing through the apparatus.

The mean difference of temperatures shown is about 30°, the range being from 210° maximum to 155° minimum for the flow, the last corresponding to an outside temperature of 50°. The main outlines of the water curves may be seen to correspond to the conditions of the weather, rising when the temperature falls and falling when the outside temperature rises.

The sharp projections and angles are due to the action of the "Converter," the greatest proportion of heat being taken from the exhaust steam from the engine running the dynamo, so that the heat in the water in the morning is generally in excess of that later in the day.

During the part of the month of May, 1889, when less heat was required on the building, it was supplied wholly by the exhaust steam with no fire under the water boiler, the water circulating at a temperature of 150° flow, 130° return.

The records from which the above lines were mapped were taken four times each day (except the upper line).

In the test of circulation in the table below, the full range of temperatures is shown under which the apparatus is intended to be operated, when all the rooms in the building are under heat. These tests also show the rapidity with which the circulation can be established, and the pressures in the apparatus corresponding to the different temperatures; the pressure due to the head of cold water, standing eighty-six feet above the boiler in the apparatus, being thirty-eight pounds per square inch when the water is cold, and 50 pounds at the excessive temperature of 252°. *The average rise in pressure is* 1 *pound for each* 10° *of temperature.*

The proportion of space under heat that was on the boiler during the month of December is as follows: —

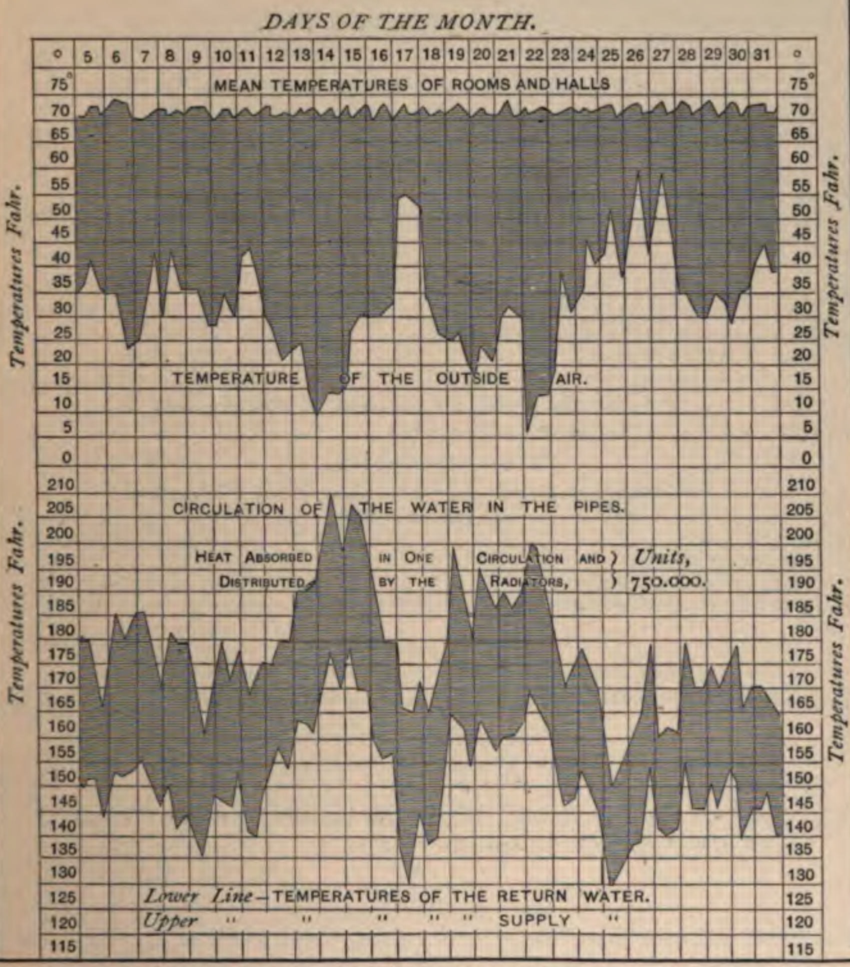
Number of rooms, 50; cubic feet, 195,209; average per room, 3,800; space in halls and unoccupied rooms, 179,319, held at 60°.

See schedule of building, page 439.

DIAGRAM No. 22.

CONDITIONS OF WATER-HEATING APPARATUS, PIERCE BUILDING,

COPLEY SQUARE, BOSTON, MASS., DECEMBER, 1888.



RESULTS OF TESTS OF CIRCULATION FROM COLD WATER, 46°.

MILLS BOILER No. 6. (SEE PLATE No. 14.)

10.22 A. M., fire started; pressure, 38 pounds, due to head of 86 feet.
10.35 A. M., temperature, 120°; the fire coaled.
11.20 A. M., " 161°; temperature of the return, 110°; pressure, 40 pounds.
12.00 M., " 218°; " " " " 160°; " 46 "
12.45 P. M., " 252°; " " " " 209°; " 50 "
Temperature in the smoke flue, average 300°; outside air, 40° Fahrenheit.

April 5, 1888, L. R. Greene and J. H. Mills, engineers.

NOTE.—*For a rise in temperature of 25 per cent the gain in efficiency is 50 per cent.*

PIERCE BUILDING, DECEMBER, 1888.

***Heat and Fuel by Calculation and by Weight.**

STEAM SYSTEM.

For Heat to Maintain Temperatures and to Supply the Loss by Ventilation.

	Units per hour.
Glass, 1,657 square feet, at 80 units per foot	133,560
Outside wall, 2,908 square feet, at 8 units per foot	23,264
Air space, 104,000 cubic feet, at .8 units per foot (ventilation)	83,200
	240,024

Corresponding Amount of Heat Supplied by the Radiators per Hour.

1,000 square feet of surface, at mean temperature of 228: Average duty (day and night), 240 units per square foot	240,000

Coal Required for Steam Radiators.

	Pounds per day (24 h.).
For Heating first floor (as above), the heat available in the radiators being taken at 7,000 units per pound of coal (gross) consumed, 240,000 x 24 ÷ 7,000	824

For Power.

Dynamo 42 horse-power, 6 hours, 42 x 4.5 x 6	1,134
Two elevators, 8 horse-power, 8 x 4½ x 15 (in use 15 hours)	540
Heating ballroom, and hot water for sinks	204
Total as above for 24 hours	2,701

Amount of Hard Coal Burned under the Steam Boiler.

Average, per day, for the month of December	2,701

WATER SYSTEM.

For Heat for 50 Rooms and Offices under Water Circulation.

195,000 cubic feet.

	Units per hour.
Glass, 1,772 x 80	141,760
Wall (outside) 9,168 x 8	73,344
Air space, 195,209 x .8 units	156,167
Halls and unoccupied rooms maintained at 50°	140,083
	511,350

Heat Supplied by the Radiators per Hour, Average for 24 Hours.

Temperature of the water, ave., 160°, 3,409 square feet at 150 units	511,350

Coal Required for Supplying Heat.

	Pounds per day.
For heating rooms and offices in use, the heat available in the radiators being taken as 8,000 units per pound of coal consumed, 371,267 x 24 ÷ 8,000	1,114
For maintaining the temperatures of halls and unoccupied rooms, 179,319 cubic feet, at 50°, 140,083 x 24 ÷ 8,000	420
	1,534

Coal Actually Consumed.

Amount of soft coal burned under *water* heating boiler, 24 *hours*,	1,030
Heat absorbed from the exhaust steam by the water circulating through the converter (dynamo, 165 pounds, pump 330 pounds)	495
	1,525

FUEL FOR APRIL, 1889.

Screenings, hard coal at $2 per ton, 3,076 pounds = $3.07.

Soft coal at $5.50 per ton, 6,225 pounds = $17.

The above was used for heating only. Total, 9,300 pounds.

Amount for *heating* during the month of December, 27,997 pounds, or a consumption of about one third as much coal under the water boiler during the month of April as during December.

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* See preceding diagram, also page 430.

TABLE NO. 16.

THE BUILDING OF S. S. PIERCE & CO., COPLEY SQUA

(SEE FRONTISPIECE.) HEATING APPARATUS (WATER AND STEAM CIRCULATIONS, MILLS SYSTEMS), BOSTON, MASS.,

CONTENTS OF ROOMS AND STORES in cubic feet, 451,176 } 551,108
" " HALLS AND CORRIDORS " " 99,932 }

FLOOR SPACE OF ROOMS in square feet, 39,188 } 50,424
" " " HALLS " " " 11,236 }

WALL EXPOSURE in square feet, 20,102 } 25,1
GLASS " " " " 5,091 }

DESCRIPTION.	No.	Cubic Feet. Contents.	Square Feet. Wall.	Square Feet. Glass.	Square Feet. Rad.	Proportion.
STEAM HEAT.		**FIRST STORY. 12 ft. high.**				
Main Entrance	A	9,750	155	25	180	
S. S. Pierce & Co.	B	37,400	871	590	374	1:100
Dartmouth St.	C	16,200	751	122	112	1:145
Huntington Ave.	D	22,650	342	414	144	1:157
Post Office	E	18,200	789	506	190	1:96
Ball Room, 65,664		104,200	2,908	1,657	1,000	1:124
Total, 169,864						
WATER HEAT.		**SECOND STORY. 12 ft. high.**				
Hall		25,200	115	35	108	
Office, Rear	1	4,308	404	34	72	1:60
" R.	2	3,456	134	40	56	1:62
"	3	4,900	294	60	123	1:40
"	4	2,904	102	20	72	1:40
"	5	5,808	224	40	144	1:40
"	6	3,696	184	20	72	1:51
"	7	5,040	140	40	72	1:70
"	8	9,120	564	114	144	1:63
"	9	2,880	92	34	63	1:46
"	10	5,184	156	60	72	1:72
"	11	2,880	92	34	63	1:46
"	12	3,168	124	20	72	1:44
"	13	5,220	400	56	128	1:41
"	14	2,392	268	38	40	1:65
Gents' Toilet		2,808	154	56	52	1:51
Ladies' "		2,124	142	20	25	1:85
		91,288	3,589	721	1,378	1:55
WATER HEAT.		**THIRD STORY. 11 ft. 6 in. high.**				
Hall		9,384	142	42	72	
Office, Double	16	7,369	447	111	135	1:56
"	17	4,968	148	59	72	1:69
"	18	2,829	105	33	58	1:49
"	19	2,929	119	19	72	1:41
"	20	5,520	384	53	112	1:49
" Rear	21	2,691	276	40	40	1:67
		35,690	1,621	357	561	
WATER & STEAM HEAT.		**THIRD STORY — Concluded.**				
Brought up		35,690	1,621	357	561	
Ball Room		65,664	1,567	226	360	
Banquet Room		10,166	397	98	128	1:79
China Closet		1,000	121	39	27	1:37
Reception Room		3,323	218	58	72	1:46
Ladies' Room		3,630	239	14	45	1:81
		119,473	4,163	792	1,193	1:57
WATER HEAT.		**FOURTH STORY. 11 ft. 6 in. high.**				
Hall		9,384	141	49	72	
Office	22	4,140	145	19	67	1:62
"	23	5,439	503	78	112	1:49
"	24	2,829	88	33	49	1:58
"	25	4,968	164	43	56	1:89
"	26	2,829	105	33	49	1:58
"	27	2,829	119	19	56	1:51
"	28	5,520	382	55	96	1:57
" Rear	29	2,691	271	39	40	1:67
Gents' Room		3,328	132	58	72	1:46
Toilet		2,142	283	39		
Janitor & Kitchen		7,038	569	98	117	1:60
Pantry		1,000	128	39	27	1:37
Musicians' Room		720				
		54,857	3,030	602	813	1:58
WATER HEAT.		**FIFTH STORY. 11 ft. high.**				
Hall		24,156	132	36	63	
Office, Rear	30	2,430	96	30	56	1:43
" R	31	4,201	384	45	105	1:40
" R	32	2,970	140	30	49	1:61
"	33	4,900	305	41	72	1:68
"	34	2,662	91	30	52	1:51
"	35	2,662	106	15	52	1:51
"	36	4,400	171	27	101	1:44
"	37	2,662	100	15	72	1:37
		51,043	1,525	269	622	
WATER HEAT.		**FIFTH STORY — Concluded.**				
Brought up		51,043	1,525	269	622	
Office	38	4,400	135	30	72	1:61
"	40	7,524	481	100	136	1:55
" Double	41	1,716	157	25	49	1:35
"	42	2,904	90	25	49	1:59
"	43	4,752	153	45	56	1:85
"	44	2,904	96	25	49	1:59
"	45	3,036	107	15	56	1:54
"	46	5,280	373	45	104	1:51
"	47	2,574	179	45	40	1:64
Gents' Toilet		2,805	293	26		
Ladies' Toilet		1,820	69	13		
		90,758	3,658	663	1,233	1:54
WATER HEAT.		**SIXTH STORY. 10 ft. high.**				
Hall, 6th & 7th		22,058	112	166	113	
Office, Rear	48	1,105	128	42	56	1:73
" R	49	4,105	345	45	112	1:37
" R	50	2,268	105	15	45	1:50
" R	51	1,680	50	10	67	1:25
"	52	4,410	109	21	72	1:61
"	53	3,748	20	10	49	1:76
"	54	4,005	127	30	67	1:60
"	55	3,696	74	30	52	1:71
"	56	5,880	18	17	81	1:73
"	57	6,762	247	43	72	1:94
"	58	2,880	120		40	1:72
"	59	5,440	250	80	90	1:60
"	60	2,457	322	45	45	1:55
Gents' Toilet		2,562	290	30	49	1:52
		76,056	2,377	584	1,010	1:61
WATER HEAT.		**SEVENTH STORY. 10 ft. high.**				
Office	61	5,100	140	20	72	1:71
"	62	4,896	98	33	67	1:73
"	63	4,480	141	19	52	1:86
		14,476	379	72	191	1:77

Data for Dec., 1888, to accompany Diagram No. 22. Heating Systems and Radiating Surfaces - - - - - 6,819 square feet. Difference cost of steam over water, 25 per cent.

WALWORTH MANUFACTURING COMPANY,

16 OLIVER STREET.

BOSTON, April 23, 1889.

Gentlemen: I submit herewith a report of heating apparatus and other work performed by Mr. John H. Mills at the Pierce Building; such operations being now practically completed.

Inasmuch as the adoption by Mr. Pierce, of the Mills' system of hot-water heating for that building, was advised by the Walworth Manufacturing Company, I deem it only justice to all parties, and the relation we bear Mr. Pierce as a customer, to make a formal report on my observations upon the apparatus as now constructed, and call your attention to an analysis of the charges therefor; which latter show quite conclusively the comparative cost between a hot-water apparatus as designed and put in by Mr. Mills and the cost of a steam apparatus as originally contemplated and estimated by myself; and it is but fair to say that, until a very short time, Mr. Mills was not aware of the amount of such estimate made by me.

Having provided Mr. Mills with a copy in detail of our charges, I requested him to analyze it, and separate from the mass such items as were not included in the heating apparatus proper, and were not estimated upon in my original figures; which service he has performed, under different headings; to each of which I call your attention, merely remarking that there has been added boiler power sufficient for electric lighting and other power purposes; an electric plant put in sufficient to light the building with 400 lights, sixteen candle-power, with duplicate pipes, foundations, and preparation for a duplicate apparatus if required; also pipes and apparatus for fire service, and for the protection, by means of steam pipes, of the roofs and gutters from ice.

The heating apparatus which he has put in, also includes a system of ventilation not contemplated at all by myself in the original figures; the covering of steam pipes and of tanks with a non-conductor, wherever necessary; furnishing all tools for the operation of the apparatus; the supplying of all steam and exhaust pipes necessary for the power added, and the temporary heating and care of the building during its construction the past winter.

The apparatus originally contemplated was a plain "direct" low-pressure steam-heating apparatus, having none of the rising pipes concealed, but all exposed in the rooms, and the employment of the wrought-iron tube radiator, placed on blank spaces of the walls wherever such suitable space could be found and utilized. Such apparatus would no doubt properly warm the spaces intended, and would have been no less unsightly than the ordinary apparatus in any commercial building, and no less "in the way." In other words, as objectionable as such things usually are. To have made it less objectionable, or more sightly, by concealing the pipes, screening the radiating surface, making it of such heights as to adopt it to the recesses under the windows, would have added an item to the cost, which at the time of giving the matter consideration, I did not deem advisable.

I did not include many of the other things that Mr. Mills has performed, and which go to make up, as seen, nearly one half of the total amount expended.

On the 5th of April last I spent the day in the building, making such observations as would familiarize me with the apparatus, and taking some interesting data with the apparatus in operation; and I do not hesitate to say that we ourselves, acting as agents for Mr. Pierce, and Mr. Pierce himself, as our customer, may well feel gratified with the result of our decision in the adopting of the water system, and the results obtained thereby.

I call your attention to one particular feature: the apparatus, as constructed, may be either a steam-heating or a hot-water apparatus, or it may be part one and part the other, and is the only instance of the kind ever brought to my observation.

Mr. Mills has put in what he calls an "absorber," so that all waste heat from the exhaust steam, that may be used for any purposes whatever, is recovered and turned back into the *heating apparatus*. All the heating pipes above the basement are concealed; the radiators are placed in recesses under the windows, and the whole apparatus is as little objectionable to the view as it is possible to construct such things. It is easily controlled, and very simple in operation. Proper ventilation has been provided for many rooms, especially for the large hall, containing about 65,000 cubic feet.

The hot-water apparatus must of necessity be noiseless, and is certainly much more economical in fuel than any steam apparatus can be, because of its greater range of adjustability; and *I do not hesitate to say that in a steam apparatus, had I estimated to secure the same desirability of form and other advantages accomplished by Mr. Mills, the cost would have been very much in excess of what our charges now are.*

My original estimate for the heating apparatus as described, was stated by me to Mr. Pierce at $9,000. An analysis of our charges, leaving all uncertain and unknown quantities as a charge against the heating apparatus, still leaves a sum under my estimate of $27.39; a result so gratifying that I think both our client and ourselves have much reason for congratulation.

In this connection it may reasonably be supposed that with such economical construction as is proven in the cost of the heating apparatus, the other charges, under the separate headings enumerated, as is shown in Mr. Mills' report, are also correspondingly economical, and that the total charge of $7,120.59 (being the total under the eight different headings not included in the regular heating) should also be satisfactory. I have examined each of these charges in detail, and so consider them.

Yours very truly,

LEVI R. GREENE, *Constructing Engineer.*

NOTE.— There were further charges and credits made against this building from April 1 to July 15, bringing up the total to balance all accounts,	$20,331.76
Credit by stokers removed, and sundries	618.00
	$19,713.76
Deduct extra charges, not in the original estimate	9,585.00
Leaving *for Regular Heating Steam and Water*	$10,128.76

Still the showing is not unsatisfactory; we see that the total cost is small compared with the class of work and material in other buildings.

Cost of the complete apparatus per square foot of radiator (both systems) .	$1.48
Per 1,000 cubic feet of space warmed (both systems)	18.00

SCHEDULE OF EXTRA ACCOUNTS REFERRED TO.

1. Increase of boiler power and plant for electric lighting, *which includes the absorber* (588.75)	$2,588.75
2. Fuel and care of the building, 9½ months (heat day and night) . . .	3,085.16
3. Ventilation of ballroom, banquet-rooms, and stores, etc.	1,346.71
4. Engine service, steam supply, and exhaust to the roof	810.48
5. Elevator's water supply from the street	634.71
6. Pipe and tank covering (asbestos air space)	400.31
7. Fire service, including automatic sprinklers in elevator well	390.81
8. Roof protection from ice, steam piping boiler to roof	216.32
9. Tools and boiler-room expenses	106.54
10. Tank, hot-water supply to the building for sinks	150.00
	$9,585.00

HAMPDEN COUNTY JAIL AND HOUSE OF CORRECTION.*

The distinguishing features of the plant are the distances from the boiler-room to the main buildings, three in number, and the fact that the water is flowed *downward, under ground, and ignores all levels, heights, and distances*, circulating perfectly through over 600 feet of main supply, or 2,000 feet of supply and return pipe, the friction of which has to be overcome; also the loss of heat due to such a distance, with many of the supply and return lines used as heating surfaces. This pipe surface is (see table) 1,700 square feet, while we may note: *Water system, heating surface to space warmed*, 1 *to* 88; *steam*, 1 *to* 70.

Plate No. 43 is a sectional view through the boiler-room, tunnel, men's cellroom, and workshop; it also shows one radiator on the chapel floor over the workshop, which is the highest point to which the water is flowed.

The main flow pipe is seen rising from the boiler to the expansion tank located under the roof of boiler-room, this point being 34 feet above the lowest point to which the water *descends* before entering the tunnel. The down flow and horizontal pipe through the tunnel is 7 inches to where it branches inside the men's prison; but the vertical risers from the boiler to the expansion tank and the return inlets to the boiler are only 5 inches, *so that the total heating surface, over six thousand square feet, is served through a five-inch pipe*, the whole length of the main flow and return pipes being over 1,200 feet.

After entering the men's prison, the main flow divides into two 5-inch *rising pipes*, one on each side of the cell block; the horizontal line which it supplies lying, as seen, immediately below the corridor walk for the first tier of cells, or say 10 feet from the floor.

The 4-inch distributing line encircles the entire cell block, two lines passing from this room (200 feet long) into the bathroom, and so on into the workshop (over 100 feet long), the chapel being above the workshop, as shown.

The other ends of the 4-inch lines pass to the front, and make a descent at an angle of 45°, to enter below the floor of guardroom; this line also serving the women's prison and the *indirect radiators* 2,000 feet.

POWER TO BEGIN AND TO CONTINUE CIRCULATION.

With water cold in the pipes at 60°, and heated to 220° in the boiler, and the vertical pipe above connecting with the expansion tank (as shown in plate 43), the head effective to start the circulation is that due to columns of water 34 feet high, one at 60° and the other at 212°, or 17.14 inches, more than 8 times the head required to maintain flow when circulation has once been established.

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* Plates Nos. 43 and 44.

PLATE No. 43.

Hampden County Jail and House of Correction, Springfield, Mass., 1887.

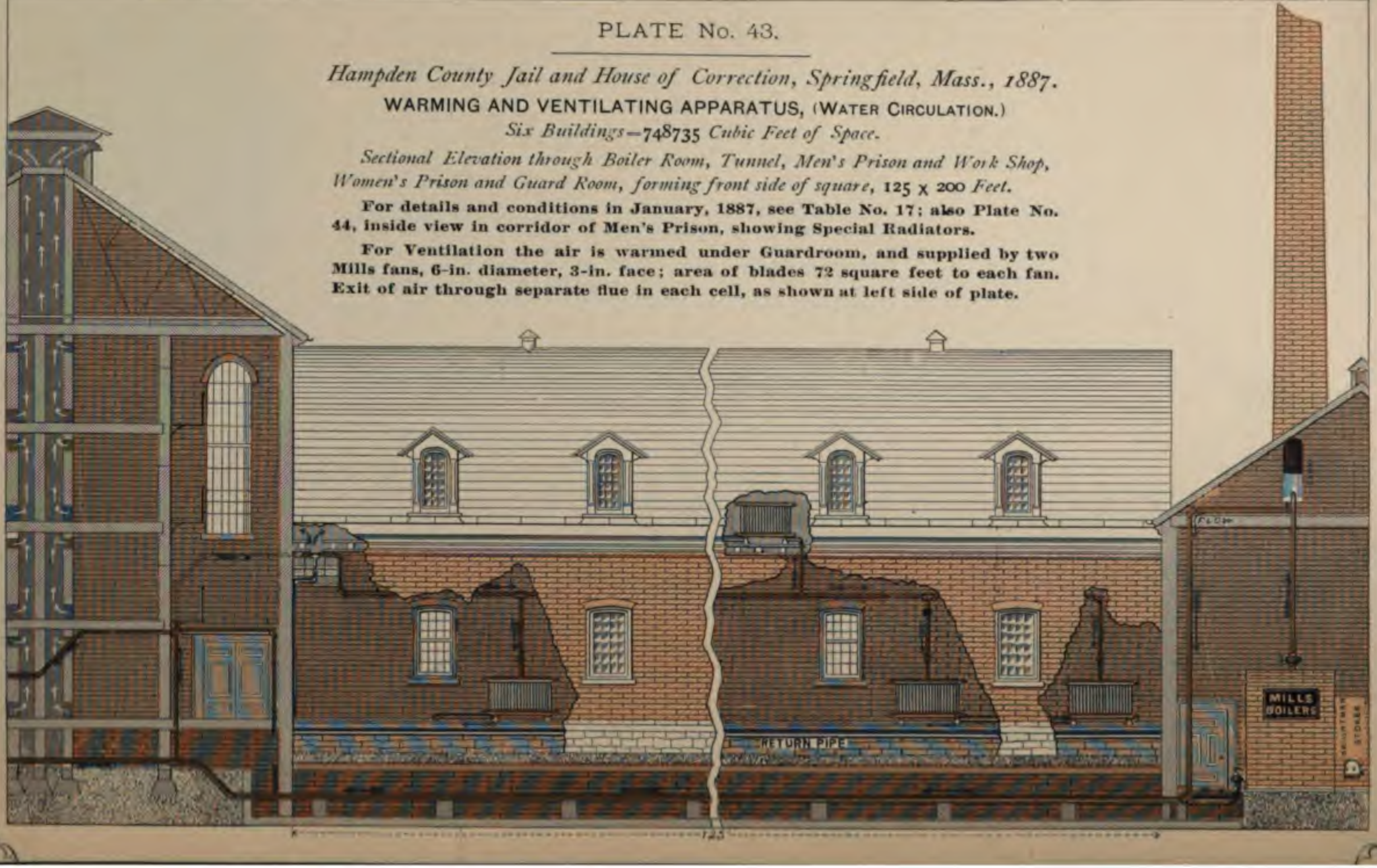
WARMING AND VENTILATING APPARATUS, (WATER CIRCULATION.)

Six Buildings—748735 Cubic Feet of Space.

Sectional Elevation through Boiler Room, Tunnel, Men's Prison and Work Shop, Women's Prison and Guard Room, forming front side of square, 125 x 200 Feet.

For details and conditions in January, 1887, see Table No. 17; also Plate No. 44, inside view in corridor of Men's Prison, showing Special Radiators.

For Ventilation the air is warmed under Guardroom, and supplied by two Mills fans, 6-in. diameter, 3-in. face; area of blades 72 square feet to each fan. Exit of air through separate flue in each cell, as shown at left side of plate.



After the water, acting under this impetus and local circulation, has reached the radiators, it is cooled in passing these and the pipes before returning to the boiler from 30° to 70°, according to the state of the weather, the mean temperature not falling below 190° in the coldest weather.

The average height of all the radiating surface above the lowest water in the boiler where heat is applied is about 12 feet.

The head to produce motion due to the excess of weight of water in the radiators and return pipes is about 2 inches if we consider the mean difference of temperature between the supply and the return to be 40°.

The friction cannot be exactly computed for the whole apparatus, the principal main being divided into two 5-inch branches, and these again supplying numerous minor circuits, which again *return to* two principal branch lines, uniting in a return 7-inch main in the tunnel. We may, however, estimate the consumption of head for the principal mains in the tunnel.

Assuming that 1 square foot of radiating surface cools 10 pounds of water 20° per hour, the whole surface, 6,000 square feet, will cool 30,000 pounds 40° each hour, and 30,000 pounds will be the required flow through the principal main, equivalent to a circulation of all the water in the apparatus, 60,000 pounds, once every two hours. This requires a velocity in the 7-inch main of about 30 feet per minute; and with this velocity the head consumed by 340 feet of 7-inch pipe equals .45 inches; leaving 1.55 inches to maintain the circulation in the branch mains beyond the tunnel.

Plate No. 44 is a perspective view through one side of corridor of the men's prison, showing the four tiers of cells and the large glass and wall exposures which are taken care of by the heating surfaces. This view also shows the 4-inch supply line and the two branches which carry the eight radiators (65 feet each), which, with the 200 feet of the supply and return lines, give us only about 700 square feet of direct heating surfaces, the contents of this part of the room being 100,000 cubic feet.*

As this amount of heating surface is only about 1 to 140, we may consider the rest of the heat as coming from the indirect radiators (under the guardroom); but, even with this addition (table No. 17), it only brings up the proportion to *one foot of water radiator to eighty cubic feet of space, warmed and ventilated.*

In this view may also be seen the warm-air supply from the fan at A. The discharge flues from the cells are seen at left of plate No. 44. For number and area of these, see table No. 16, page 439.

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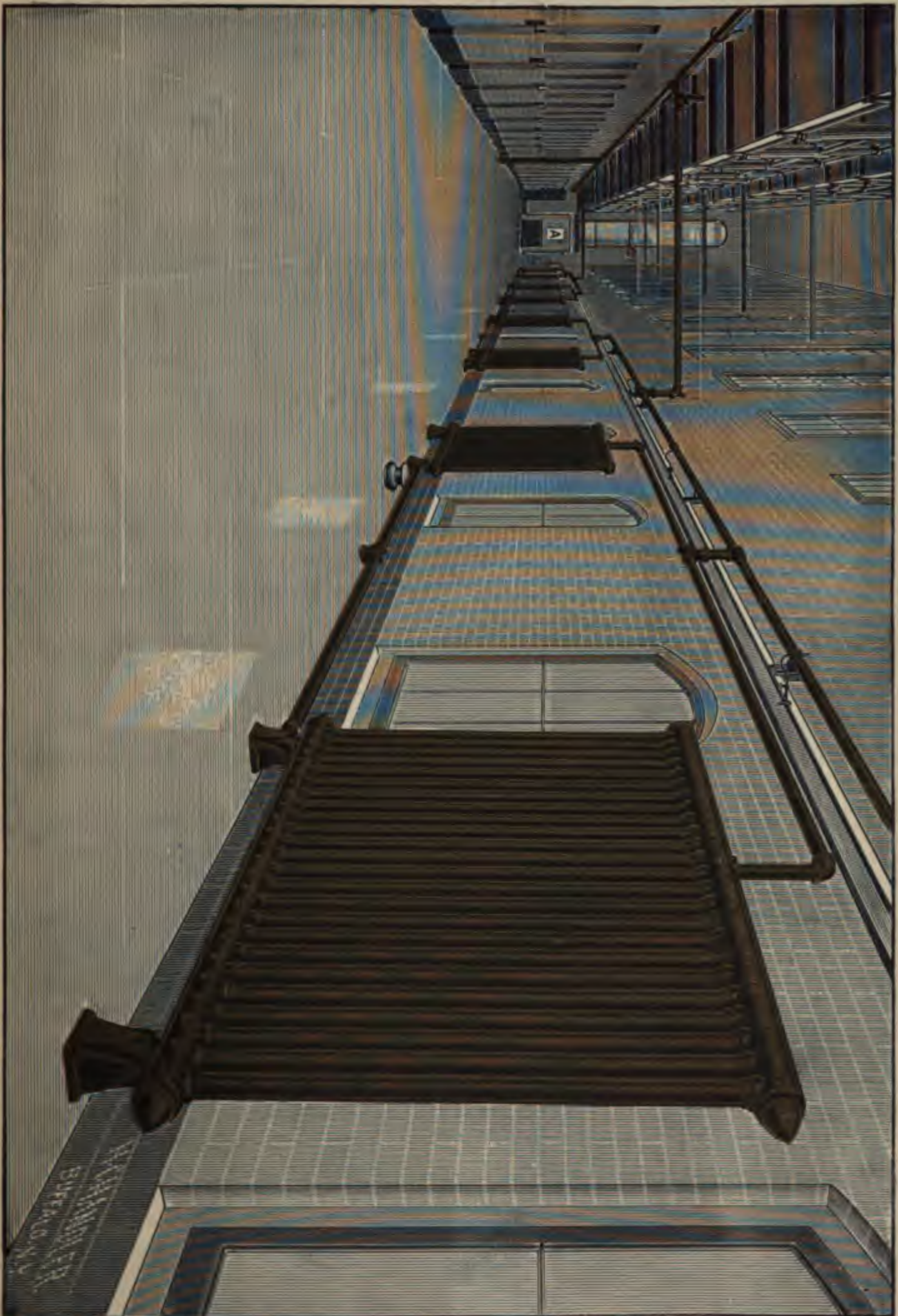
* This indirect heat chamber not shown on the plate is located beneath the guardroom (60 feet away), and the air warmed there for ventilation is delivered into the cell block by fan. (See Commissioner's letter, page 448; also drawing of fan, page 503, vol. 2, chapter on Ventilation.)

PLATE No. 44.

Hampden County Jail and House of Correction, Springfield, Mass., 1887. Radiators and Piping for Water Circulation (Mills' System).



View through one side or half of Cell Block, Men's Prison, looking towards the Guard Room.

Pure Air Supply from Indirect Heat Chamber and Double Mills Fans at A. (See Table 17.)

ACTUAL CONDITIONS HAMPTON COUNTY JAIL JAN. 19, 1887.

Outside, 7 A. M., 6° below zero; 12 M., zero; 5 P. M., 10° above.
Temperature of the flow, 235°; of the return, 150°.
Mean temperature of the water, 192°. Pressure, 30 pounds.
Temperature of the main supply at the workshop, 195°.
Temperature of the guardroom, 70°.
Temperature of the men's prison, 68°; of the women's prison, 67°.

For all the other days of January see the following table, which includes the fuel for all the uses of the institution.

Of the whole space warmed, 748,735 cubic feet, not quite one third, or 200,000 cubic feet, was served with steam heat from the same boiler-room. This, because it was necessary to have one steam boiler for the cooking and laundry, baths, and water heating; and it was deemed desirable to place the sheriff's dwelling and guardroom on the same steam system. These spaces gave (as seen in table, upper right-hand section) 2,500 as the corresponding heating surface on the steam system, and 6,224 on the water system.

Following down, we note the fuel that each system required each day, and we see that the cost of fuel was nearly as much for the steam as for water heat, and that for certain days, as the 16th, the 23d, the 28th, and the 29th, the fuel was the same, so that finally we read (table lower left-hand section):

Cost of warming 1,000 *cubic feet of space at equal distances and exposures: Steam,* 3.7 *cents; water,* 2.4 *cents, or* 34 *per cent less for the water than for the steam heat.* Now, if we credit the steam for the laundry and baths, etc.,—say 20 per cent of the whole,—*we shall still find that the water heat was* 20 *per cent cheaper than the steam.*

That this is near the fact, is proved by examination of similar conditions and results found at the Pierce Building for the month of December, 1888, where we read (table No. 16, lower section, page 441):

Steam system, 169,864 cubic feet; water, 374,000. Cost for warming 1,000 cubic feet of space 24 hours: Steam, 2.37 cents; water, 1.9 cents, or 20 per cent less. The disparity in the total cost of heat in the two locations is due—first, to the great distances of the heat from where it is used; second, to the fact that the Springfield plant is partly *indirect*, to furnish ventilation created by fans,—and partly to *the economy secured at the Pierce Building by absorbing the exhaust steam from the elevator pumps and dynamo into the water circulation.* This was referred to in another place (page 435 and 438).

The following letter of the Commissioner furnishes much other and relating data, both as to the operation of this plan and comparison of steam and water apparatus.

TABLE No. 17.

CONDITIONS OF WARMING AND VENTILATING HAMPDEN COUNTY JAIL, SPRINGFIELD, MASS., 1887.

Six Buildings = 748,735 Cubic Feet of Space.

Ventilation Effected by Mills's Fans, Actuated by Water Motor with Hydrant Pressure of 100 lbs.

Air Changed Once Each 45 Minutes. Air Inlet 40 Square Feet, Area of Discharge 80 Square Feet.

Guard Room, cubic feet,	89,553
Jailer's Residence, cubic feet,	42,000
Hospital, cubic feet,	50,780
Chapel, cubic feet,	34,580
Men's Cell Room, cubic feet,	249,172
Men's Work Room, cubic feet,	65,552
Bath Room, cubic feet,	16,170
	547,807

Brought Forward,	547,807
Women's Cell Room,	88,744
Women's Work Room,	48,004
Laundry,	21,620
Kitchen and Bakery,	10,000
Bucket Room,	7,560
Basement,	25,000
Total Space in Cubic Feet,	**748,735**

HEATING SURFACES, WATER SYSTEM.

Direct Radiators, 41; Average, 63;	2,586 sqr. ft.	
Pipe Surface Supply Lines,	1,790	
Indirect Radiators, 231 G.P.,	1,848	**6,224**

SURFACES, STEAM SYSTEM.

Direct Radiators, 22,	1,021	
Pipe Surface Supply Lines,	1,019	
Indirect Radiators, 46 G.P.,	460	2,500
Total Heating Surface in sqr. ft.,		**8,724**

Outside Temperatures, Direction and Force of the Wind.

1887.		7 A. M.			2 P. M.			9 P. M.			Outside	Inside	Diff.	Fuel in lbs., water heat.	Fuel in lbs., steam heat.	Cost of fuel, water heat.	Cost of fuel, steam heat.	Total cost, water and steam.
Jan.	14	25°	N.E.	Mod.	23°	N.	Light.	20°	N.E	Light.	24°	69°	45°	2880	2640	$7.20	$6.60	$13.80
"	15	15	N.E.	Light.	21	N.	Mod.	21	N.	Mod.	19	"	50	3700	2800	9.25	7.00	16 25
"	16	22	N.	Heavy.	27	N.	Light.	20	N.	Heavy.	23	"	46	3360	3200	8.40	8.00	16.40
"	17	22	N.W.	"	22	W.	"	25	N.W.	Mod.	23	"	46	3360	2880	8.40	7.20	15.60
"	18	17	S.	Light.	17	S.E.	"	B.Z.-1	"	Light.	16	"	53	3840	3280	9.60	8.20	17.80
"	19	B.Z.-6	E.	"	13	"	Mod.	14	N.E.	"	7	"	62	4720	3840	11.80	9.60	21 40
"	20	9	W.	Heavy.	24	N.W.	Heavy	30	N.W.	"	31	"	38	3760	3040	9.40	7.60	17 00
"	21	38	N.	"	35	E.	Light.	26	S.E.	Heavy.	33	"	36	3440	2800	8.60	7.00	15.60
"	22	12	S E.	Mod.	28	S.E.	"	40	"	Mod.	27	"	42	3120	2880	7.80	7.20	16.00
"	23	40	"	"	46	N.	Mod.	45	N.	Light.	44	"	25	2400	2400	6.00	6.00	12.00
"	24	47	S W.	Heavy.	40	S.E.	Heavy.	29	S E.	Mod.	39	"	30	2000	1760	5.00	4.40	9.40
"	25	24	S E.	Light.	35	N.	"	39	N.	Light.	33	"	36	2640	2400	6.60	6.00	12.60
"	26	39	N.	"	31	S.E.	Mod.	17	"	Heavy.	29	"	40	2400	2000	6.00	5.00	11.00
"	27	5	S.	Heavy.	17	"	Light.	13	"	Mod.	11	"	58	3280	2960	8.20	7.40	15.60
"	28	19	"	Light.	40	W.	"	43	W.	Light.	34	"	35	2560	2560	6.40	6.40	12.80
"	29	46	S E.	Heavy.	41	S.E.	Heavy.	35	S.W.	Heavy.	40	"	29	2480	2480	6.20	6.20	12.40
"	30	33	W.	Light.	36	"	"	36	"	Light.	31	"	38	2720	2560	6.80	6.40	13.20
"	31	25	"	"	26	N.W.	"	22	N.	Mod.	24	"	45	3040	2960	7.60	8.20	15.80
														3094	**2747**	**7.73**	**6.87**	**14.60**

Cost of warming 1,000 cubic feet space 24 hours: *Steam*, 3.7 *cents*, *water*, 2.4 *cents* = 34 *per cent less*.
Water system, *Wall* exposure in square feet: 18013; *glass* exposure, 8978 = 26991. **Steam system**, *Wall* exposure in square feet: 5651; *glass* exposure, 2030 = 7681. (See also table No. 16.)

MISCELLANEOUS.

WATER SYSTEM, cub. ft., 548,735, Radiator 6224 = 1 to 88

STEAM SYSTEM, cub. ft., 200,000, Radiator 2500 = 1 to 80

Coal burned under two 60 H. P. *Mills Safety Sectional Boilers*, using *Brightman Mechanical Stokers* = 30 square feet grate. Size of water supply and return pipe, 6 inches. Steam supply pipe, 3 inches; return pipe, 1¼ inches, to hot well. (See also table No. 7.)

OFFICE OF

COMMISSIONERS OF HAMPDEN COUNTY,

SPRINGFIELD, June 9, 1889.

TO WHOM IT MAY CONCERN:—

The undersigned, having in charge the construction and equipment of a new Jail and House of Correction for this county, found—as other boards of construction have, and will continue to find—that the warming and ventilation of such buildings was a problem of no small magnitude.

The board in office in 1887 had for some years the care of the old Jail structures on Main Street, and the then quite recently erected building on the Square for county and court uses.

In both these buildings, steam was the means of warming, planned and put into them on construction. The arrangements at the Jail buildings, besides warming, required steam for cooking, laundry, and dry-room purposes.

The plant of the old Jail consisted at first of one, and later of a second, wrought-iron tubular boiler; these were run on the high-pressure principle, to serve the kitchen and laundry uses. Steam for heating the several buildings was "reduced" in pressure, and supplied to coils in the usual way—the water of condensation being returned to a *hot well*, and pumped back into the boiler to supply the waste.

The arrangements, when new and under the care of an educated engineer, did very well, although they kept somebody on the constant watch and work, to get the several uses and demands for steam and heat properly administered. Later, when the boiler and pipes, pump, traps, and coils had become worn by use and friction, it became the almost constant care of an officer to keep this *capricious and dangerous element up to its required duties. To do this many changes and much expense for repairs were yearly incurred; besides there was the ever-present danger of over-pressure and explosion.*

The arrangements for warming at the new Court House, a structure of stone three stories high, and containing over *four hundred thousand cubic feet of space*, was that known as the low-pressure system, with return of the condensation to the boilers, which were of wrought iron and located in the basement. The radiators for supplying the main part of the heat were also placed in the basement and supplied with air from without the building.

This was a modern and presumably perfect steam heating and ventilating plant, erected by persons skilled in such construction, at a cost of over $10,000.

A short use of the apparatus, however, proved that there was much to be desired and supplied before the wants of the different occupants of the building could be met.

It was soon discovered that the boilers were too small, were improperly set, and poorly connected to the radiators; that the draught could not be relied upon, owing to defective chimney arrangements; and that finally the ventilation, while much talked about, *was a total failure.*

This state of things was endured several years, with constant changes, bringing bills for repairs all to no practical purpose, until finally the judges of the Superior and Supreme Court rooms fairly revolted, and struck for proper heat and ventilation.

In this state of the case, the board availed themselves of the services of a constructing and ventilating engineer, John H. Mills (then of Buffalo), who, after a careful survey of the premises, made plans for the reconstruction.

These included new and larger boilers, a rearranging of the indirect heat, and a system of *mechanical ventilation*, altogether costing about $4,000. These plans were approved by the board, and the work promptly executed by Mr. Mills in 1887, *since which time there has been no deficiency in either heat or ventilation; but there has been a decided reduction in the fuel bills, and an entire abolition of expenses for repairs.* NOTE.—This reduction in cost of fuel amounts to $530 per year.

The striking and valuable feature of this improvement is the system of mechanical ventilation by an exhaust wheel placed in the attic, and operated by a small water motor in the basement, the distance between the two machines being over 150 feet.

The fan, or exhausting machine, the invention of Mr. Mills, acts not only upon the principle of the exhaust common to some other fans, but upon a different application of this principle from any other that has been brought to our notice; in the briefest phrase, *a large diameter and blade area of wheel, which, with a slow motion, removes a very large volume of air and at a small expenditure of power, and, being run by water power, may be and is used in summer as well as in winter.*

As to the cost of the water found by the bills, we think it is below $10 per month, with a water pressure of 100 pounds, the space acted upon being, as stated elsewhere, some 400,000 cubic feet.*

The above and other personal experiences with steam heat and our former method of ventilation prepared the Commissioners to consider intelligently the more extensive and difficult problems presented in the new Jail building, on York street.

These, as seen by the table prepared by our engineer, which we consider correct, with the other views and section of the heating apparatus, consist of a number of buildings constructed around a square 125 x 150 feet; the boiler-house and fuel storage being on one of the four sides, and practically on a level with the other buildings to be warmed.

Here, then, at the start, it was not found practicable to employ steam for warming in the usual manner, or with a return of the water of condensation to the boiler-room — to say nothing of getting it properly supplied to the several isolated buildings, or under control when it should once be there.

There was also the always difficult matter of air supply to the three or four hundred occupants, of a class from which nothing was to be expected in the way of intelligent use of any means provided.

With these various and different problems to meet, the board again invited Mr. Mills to consider their case and the various demands of such an extensive institution, consisting of *heat, ventilation, laundry, and cooking apparatus.*

But a short examination convinced him that a radical departure from common and existing methods of heat supply was here called for. With the former experiences of the board, they were in a situation to entertain and approve a plan of water heating, coupled with other and novel details of warming and ventilation.

This was in effect a circulation in the boiler pipes and radiators of water instead of steam, *mechanical ventilation, and mechanical feeding of the fuel to the heating boiler, a fine or slack kind of soft coal being used.*

The plans of boiler, piping, and circulation were perfected and offered to competitive bidding, only to be pronounced impracticable by both steam and water heating firms; many engineers declaring that a water circulation, as planned, was not possible to accomplish.

Still the board had confidence in their engineer, and the work was awarded to Mr. Mills for the sum of $16,000, which they considered low for the amount of labor and materials involved.

The work was promptly executed by the contractor, and the question of circulation and efficiency soon settled, although perhaps with the smallest amount of heating and radiating surfaces ever furnished to buildings of such extreme exposure, and with so large a pure-air supply.

The apparatus was put to test for the whole month of January, 1887, and for the past two winters with the most [illegible]. See table of space and conditions.

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*See bills of the wa [illegible] XX.

The heat has been constant and satisfactory in the coldest weather, affording at all times a sufficiency, without any overheat in the milder days of the autumn and spring. The total variation of temperature inside all the buildings has not exceeded three degrees.

In the workshop from one hundred and seventy-five to two hundred men are employed, so that here the demand for heat and ventilation exceeds that of any other building. It was met in the following arrangements, which included heat and ventilation for the chapel: —

The heating surfaces are about equally divided, one half being "direct" radiators, on the floors and under the windows; the other half being thirty Gold's pin "indirect" radiators, placed in a single chamber at the ceiling, and supplied with a large volume of air from without the building. Below the floor was placed a six-foot Mills fan, exhausting the air from the floor level, and discharging into the basement, thus *changing and renewing the air in both localities.* The fan is operated by water from the hydrant, which is then discharged into the jet pipe which *serves the urinals*, so that *no extra water or cost is incurred for this important duty.* The fan is run in warm as well as cold weather, and if properly attended to is the solution of the difficult problem of ventilation.

This control of the heat is one of the especial virtues of this arrangement, and is accomplished entirely at the boiler-room, and on the whole circulation, a card of heat and temperatures being furnished. The fireman is instructed and carries his water: for instance, if the outside weather is at freezing, he will flow his water at the boiling point, or 212°; if at zero, he flows it at 240°, and so the medium is always at the right temperature to meet the outside demand. Thus there is no call for opening or closing valves, and we do not think that any other government is required or employed by the officers in charge.

Of the general results we can speak in the highest terms; the whole water plant is simplicity itself, and is run much of the time by inmates of the institution. There being no steam pressure to carry or water line to watch, the whole matter of heat is in this large institution resolved into a simple matter of firing and coal supply.

While two boilers of 60 horse-power were provided, only one has been used at any time except for testing and by the contractor, while the total repairs have been a small matter of grate bars, mostly for the steam or cooking boiler.

Of the ventilation, too much cannot be said. We have examined many examples of so-called ventilation, but found nothing to compare with this apparatus in the way of volume or purity of the air in all the buildings. It has also been critically examined by the State Board of Public Institutions and pronounced in every way satisfactory.

Of this interesting part of the apparatus, we may say that the lungs of this breathing apparatus are situated in one large chamber under the front entrance, in which is nearly 2,000 feet of pin radiators; the cold air is admitted on *top of the stack, and is drawn down* through the heating surfaces by the double fans located on each side of the chamber; by this means air of any temperature and volume can be supplied to all the rooms; in fact, the fans are generally run nights in warm weather, as well as days in cold weather.

Much more might be said in approval of this invention in warming and ventilation; but we have already exceeded the limit of what we proposed to say, and will only add that the work and results have been inspected by visitors from other parts of the country, always with the same unqualified approval, while several other plans of warming and ventilation in Boston and elsewhere have been modeled from this apparatus.

LEONARD CLARK,
L. W. ROOT, C. E.
A. F. WILDER,

Commissioners
of
Hampden County.

CHURCHES.— Without intending to go at any length into church heating and the distinctive class of apparatus where ventilation must take precedence, we may briefly refer to one or two examples and contracts of the writer,— Trinity Church, Copley Sq., Boston, Mass., Rev. Phillips Brooks, rector.

This, we hardly need to say, is the largest and finest Episcopal church in the United States and perhaps in the world. The auditorium is 100 feet high from the floor to the roof of dome, contains over 500,000 cubic feet of space, and can seat from 1,500 to 2,000 persons. The chapel adjoining is a fair-sized church in itself, used for lectures and Sunday-school purposes.

The heating and ventilation of both structures were originally attempted by the use of hot-air furnaces,— a gravity supply and removal of the air for purposes of ventilation. The arrangement was, however, different from that usually followed in furnace heating, the whole basement being taken and converted into a hot-air chamber, numerous registers being cut in the floor, for delivering the heated air to the spaces above. While the theory of this simple arrangement was apparently good, the use and results were anything but satisfactory. Although four monster wrought-iron furnaces were built something like eight feet long by five feet wide, giving a heating surface of over three hundred square feet each, they were utterly inadequate to the requirements of heating and ventilation, but ample to destroy the building by fire — which they came very near accomplishing.

The present apparatus, constructed by the writer, is a hot-water circulation in boiler pipes and radiators, with a liberal pure-air supply from without the building. This is controlled by a fan in the basement, driven by a jet of water from the hydrant pipe.

The plant consists mainly of two vertical sectional boilers, with a fire surface of *eight hundred square feet and twenty square feet of grate*. The heating surfaces (radiators) amount to 5,400 square feet, of which 3,000 square feet are located in six chambers in the basement, and supplied with air from without the building; a further supply of heat and air for ventilation is by the fan, which is arranged to deliver either warm or cold air, as desired. This apparatus was used the winters of 1887–1888, and has given unqualified satisfaction to the very critical class who own and occupy the pews.

As a further reference to church heating by water apparatus, we may say that the committee of the Eliot Congregational Church at Newton Centre adopted *a duplicate* of this apparatus after careful inspection. It was put in and operated last winter while the edifice was being completed, and gave proof of its power a [illegible] lso of the *economy of a water over a steam apparatus*.

SCHOOLHOUSES.*

In diagram No. 23, for the month of February, 1886, we note how great the variations of outside temperature may be (from 5° below to 58° above zero), while not much variation of the inside heat line is noticed; the drops to 65° on the 7th, 14th, 21st, and 27th were for *Saturday and Sunday, when the fires were banked.*

The 4,000 feet of radiator divided by the 200,000 cubic feet of space in the building is 1 to 50; but a ventilating fan is used, and the air in all the rooms is regularly changed. We shall later present a table showing how much heat is contained in and carried away by the air, as this is a point not to be overlooked. Ventilation is essential and imperative in public buildings; but, like all other good things, it does cost money.

The heating and ventilation are accomplished by two distinct systems; a circulation of *steam* being used from one boiler to supply the *direct* radiators, while a circulation of *water* is obtained from the other boiler for supplying the *indirect* radiators, which also furnish the air for purposes of ventilation.

The indirect radiators are located in four brick chambers in the basement, and are divided into three stacks to each chamber, so that the amount of surface used is under the control of the janitor. Each brick chamber serves three schoolrooms located vertically overhead, the warm-air tin pipes passing up the inside partitions to the several rooms, the warm air entering about seven feet from the floor. Each heat chamber has a cold-air supply 24 inches in diameter, 452 inches, laid below the cellar floor. *The total pure-air inlet is thus twelve square feet.*

The employment of hot-water service in the *indirect* radiators, which supply the warm air to the rooms, does not allow the temperature to fall as low nights as when steam alone is the heating agent. *This arrangement also admits of a hot-water service in the sinks, a matter of great convenience in a school building.*

The constant movement of the air from all the rooms is effected by the rotary movement of a fan placed in the attic, to which all the vent flues are conducted.

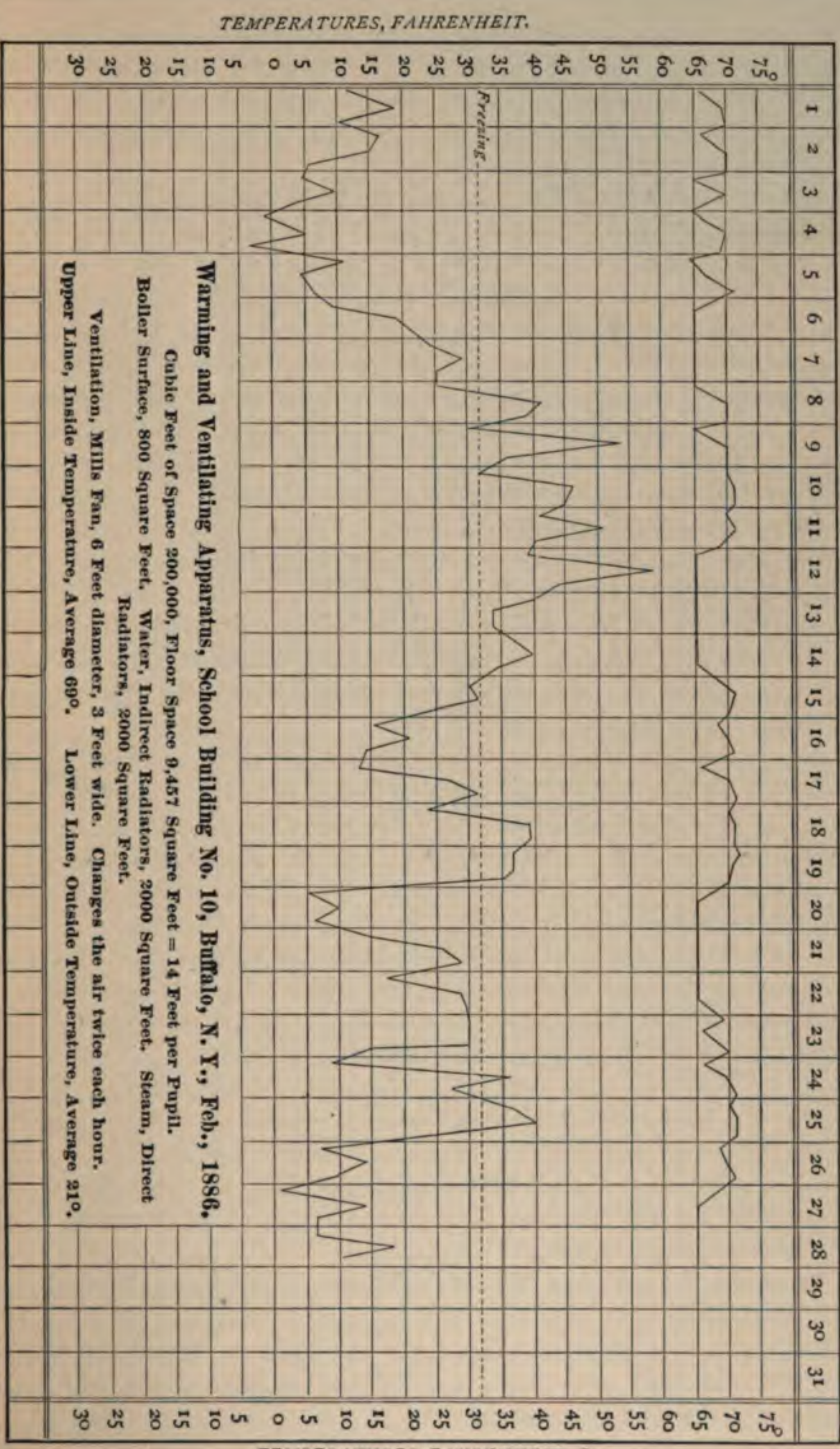
The fan is moved by a small water motor in the basement, the hydrant pressure being from 15 to 18 pounds. The fan wheel, revolving 70 times per minute, discharges 8,000 cubic feet of air per minute, and changes the air of the rooms and closets four times an hour, affording over 1,000 cubic feet of pure air per hour for each pupil.

School No. 13, also in Buffalo, is warmed and ventilated by this same system. See report of this building in the following section on ventilation; also drawings of the fan used.

NOTE. — This is substantially the same arrangement for *removal* of the vitiated air as that at the six buildings at the State Insane Asylum, Buffalo, N. Y. See page 118.

*** See report of Professor Fish in chapter on mechanical ventilation.**

DIAGRAM NO. 23. DAYS OF THE MONTH AND TEMPERATURES.



Warming and Ventilating Apparatus, School Building No. 10, Buffalo, N. Y., Feb., 1886.

Cubic Feet of Space 200,000, Floor Space 9,457 Square Feet = 14 Feet per Pupil.

Boiler Surface, 800 Square Feet. Water, Indirect Radiators, 2000 Square Feet. Steam, Direct Radiators, 2000 Square Feet.

Ventilation, Mills Fan, 6 Feet diameter, 3 Feet wide. Changes the air twice each hour.

Upper Line, Inside Temperature, Average 69°. Lower Line, Outside Temperature, Average 21°.

Passing to the consideration of the work to be obtained from a closed apparatus, circulating water in the place of steam and in the same sized boiler, pipes, and radiators, the author has collected much data from plants in actual operation, and thus what he has to offer may stand for facts in the place of theories.

The most complete of these records are those taken at Grand Rapids, Mich., at Buffalo, N. Y., at Springfield, Mass., and at Boston, Mass., with some records for private houses in various States.

The first systematic experiments on water were begun in 1881 (page 473); others have followed, and have continued up to and including the winter of 1889. It was seen that great care must be exercised in obtaining data; and to this end a set of printed blanks were employed, on which, at a stated hour and place, were entered the temperature outside and inside the buildings, the temperature of the flowing water (supply and return), also the fuel, and much other data relating to the direction and force of the wind, etc.

The main and fullest record for housework was that taken at No. 25 Niagara Square, Buffalo, N. Y. This large dwelling was leased for three years, and occupied as a residence, with the object of having a place perfectly under control and observation, so that all contemporaneous data could be secured, and it was there many of the writer's most valuable experiments were carried out.

In diagram No. 25 and in the accompanying table and diagram are collected all the items of daily operation and condition for a midwinter month. It should be noticed that this was a dwelling standing on a corner lot, one hundred and nineteen feet on Delaware Avenue, and forty feet front, two stories high; forty feet of the rear on Delaware Avenue being workshop and office.

In the plans the red dotted lines near the walls show the *three indirect heat chambers below the floor*, also "direct" radiators on the first floor; the red arrows indicate where the heat registers were located, and the black arrows the chimney flues used for ventilation.

In the following card (No. 18) the temperatures ranged from 135° to 240°. The pressures during these changes varied considerably, that due to the height of the water on the second floor being 10 pounds. The increase noted was substantially that of table No. 15 (preceding chapter), where for 240° we read 35 pounds, *an increase of* 11 *pounds for a rise of* 30° *in temperatures.*

There have been many other dwellings warmed in Buffalo by substantially the same apparatus and arrangements, with good results. The dwelling of General Graves, on the Park road, contained over 100,000 cubic feet. *The barn, at a distance, was also warmed and ventilated* by the same water circulation.

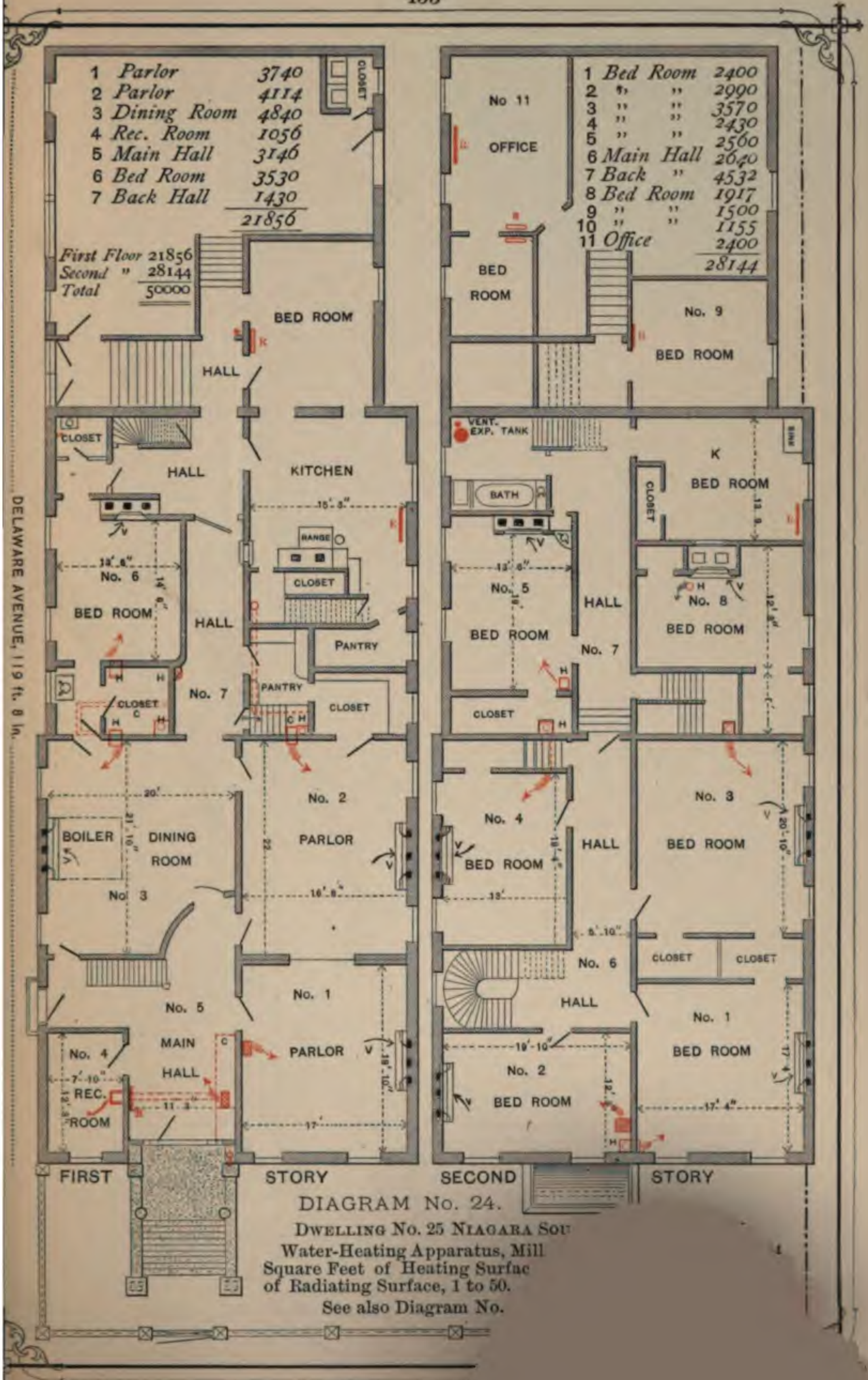


DIAGRAM No. 24.

DWELLING No. 25 NIAGARA SOU

Water-Heating Apparatus, Mill

Square Feet of Heating Surfac

of Radiating Surface, 1 to 50.

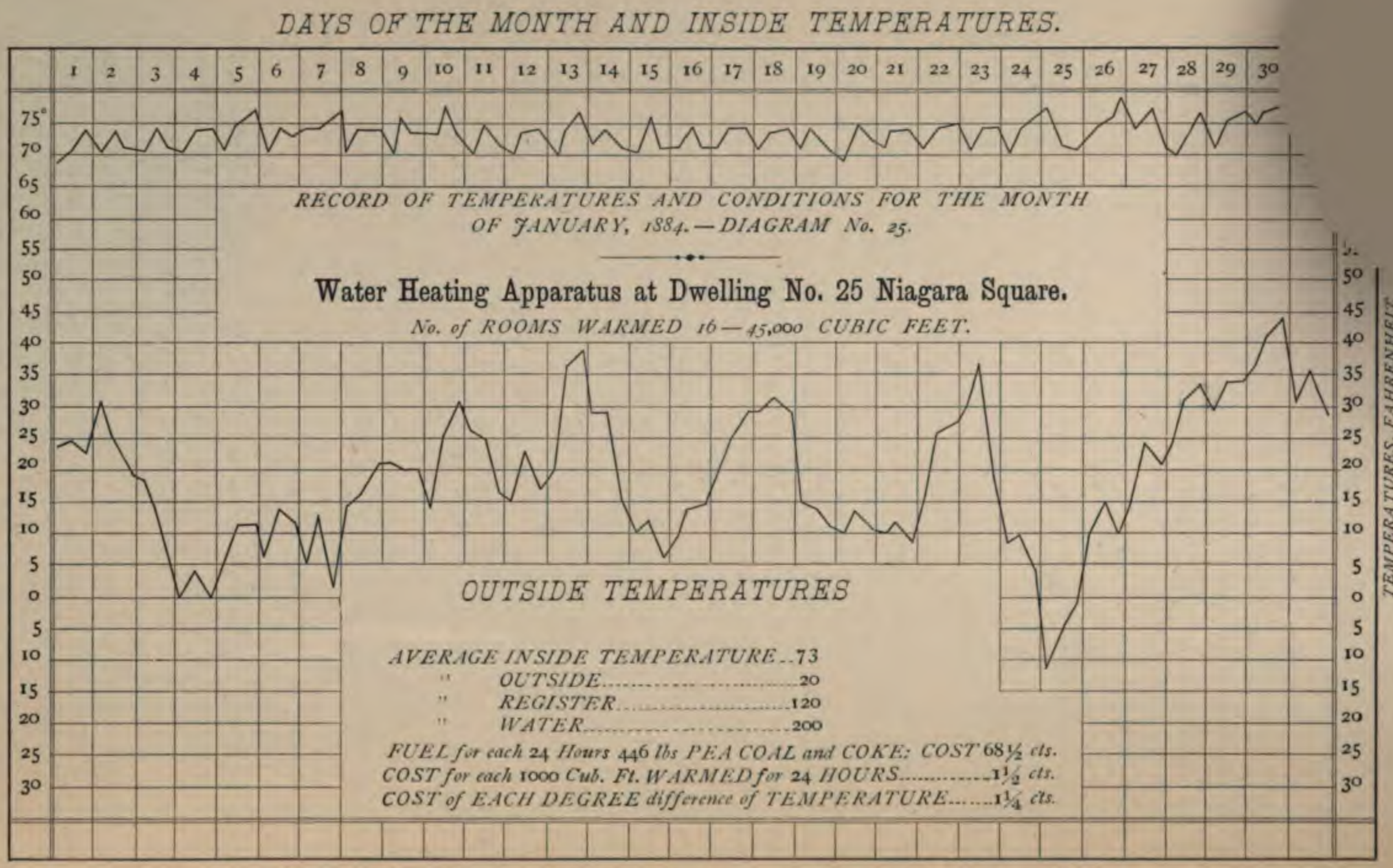
See also Diagram No.

TABLE No. 18. TEMPERATURE OF THE WATER AND FUEL CARD FOR JANUARY, 1884. *At No. 25 Niagara St., Buffalo, N. Y.*

A. M.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
6	176°	185°	194°	226°	217°	200°	185°	216°	195°	215°	219°	216°	229°	207°	210°	216°	213°	212°	217°	210°	223°	218°	201°	203°	220°	213°	216°	205°	195°	200°	195°
6.30																															
7	130 F	135 F	160 FF	180 F	160 F	160 FF	200 F	150 FF	180 F	170 F	200 F		200 F			180 F															
7.30																	220 F					190 F									
8						200 F	200 F													190 F	180 F				200 FF	180 F	190 FF	190 FF	190 FF		
8.30			205 F											205 F				190 FF	200 FF												180 F
9				240 F	230 FF				220 F	230 FF	220 F	210 F	220 F		200 F	220 F	200 FF				200 F	220 F		200 F		220 FF					
9.30						200 F														200 FF			210 F								
10	180 F							220 F					280 F		210 F															200 F	200 F
10.30							200 F																								200 FF
11									220 F		220 FF	210 F										220 FF				220 F					
11.30						200 F										200 F			220 F		210 F			200 FF			220 FF				
12		190 F	205 FF	240 FF			220 F	220 F		220 F				200 F	210 F		220 F						195 F					210 F	190 FF		
1		190 F											220 F					220 F	220 F		210 F			220 FF	220 FF			200 FF			
2	180 F							220 F	220 F								220 F			210 F		230 F	200 F							200 F	
3					240 FF		230 FF					220 F	220 F		205 F						220 FF						220 FF				
4		200 F				200 F		220 FF	220 F		210 F					230 F			220 F	220 F				200 F	230 FF	230 F					
5		195 F		240 FF	240 FF					230 FF	220 F		230 F	200 F				180 FF				220 FF	200 F				230 F	210 FF			
6	200 F		200 F			220 FF	200 F		240 F					210 F	205 F	230 F	200 FF		220 FF	220 FF	220 FF				230 F				200 FF	200 FF	200 F
7							220 F	240 F	240 F	220 F	220 F	220 F			210 F	230 F				220 FF			200 F	200 F		230 F	220 FF				
8																															
9																															
10	190 FF	200 FF	200 FF	230 FF		220 FF	230 FF	220 FF	220 FF	220 FF	240 F	220 FF		200 FFF	230 FFF	220 FFF	220 F	220 FFF	220 FFF		220 FFF	220 FFF		200 FF	220 FFF	230 FFF		200 FFF	200 FF	200 FF	
11																															
Total Coal	300	300	400	400	350	500	450	500	450	450	400	300	300	350	450	475	360	450	500	450	550	500	250	450	500	450	450	500	400	360	250

HOURS OF THE DAY.

Letters F represent each charge of fuel 50 lbs. Total fuel per day lower line.



DAYS OF THE MONTH AND INSIDE TEMPERATURES.

RECORD OF TEMPERATURES AND CONDITIONS FOR THE MONTH OF JANUARY, 1884.—DIAGRAM No. 25.

Water Heating Apparatus at Dwelling No. 25 Niagara Square.

No. of ROOMS WARMED 16—45,000 CUBIC FEET.

OUTSIDE TEMPERATURES

AVERAGE INSIDE TEMPERATURE..73
" OUTSIDE....................20
" REGISTER....................120
" WATER....................200

FUEL for each 24 Hours 446 lbs PEA COAL and COKE: COST 68½ cts.
COST for each 1000 Cub. Ft. WARMED for 24 HOURS..............1½ cts.
COST of EACH DEGREE difference of TEMPERATURE.......1¼ cts.

The preceding table shows the *fuel* and *temperatures* of the water for the same days.

It is easily seen that this was more than a common dwelling, even of the larger class, and with large *wall* and *glass* exposure; also that the heat was mainly from "indirect" radiators, with an outside supply of cold air. *Every room in the house was used as a sitting-room, and was held up to the temperature shown in the diagram.*

Under all these adverse conditions with "indirect" radiators and liberal cold-air supply, the proportion of radiating surfaces to space warmed is seen to be 1 to 50, and that this heat was furnished from 3 centrally arranged heating chambers, with a half-dozen direct radiators at the remote points.

Diagram No. 25, preceding page, is the record of the inside and outside temperatures taken three times each day, by putting a pencil mark on the point indicated by thermometer.

Table No. 18, page 456, shows every time that the furnace was coaled (F = 50 pounds of fuel), and the water temperature (flow) at the time. Thus, January first, hour 7 A. M.; first coal 50 pounds; temperature of the water 130°; all this in the same square opposite the hour 7 A. M. in the margin. The diagram of temperatures now for the same date and hour, outside the house, gives just under 25° for the day; inside, 70° to 74°, and so on for each successive day. Our lowest outside temperature is on the 25th at 11° below zero, at which time we see the inside temperature making the highest mark of the winter.

Turning to the *fuel card*, No. 18, and under that date, we see that the fire was coaled 5 times (in 24 hours), total 500 pounds, and that the water *supplying the heat was from* 200° *to* 230°, *average about* 200°; any other day and results may be traced in the same way.

Where the cost of fuel is greater, the expense would be a little more; but we must remember that this was an *extreme exposure, and nearly all indirect heat with large outside air supply.*

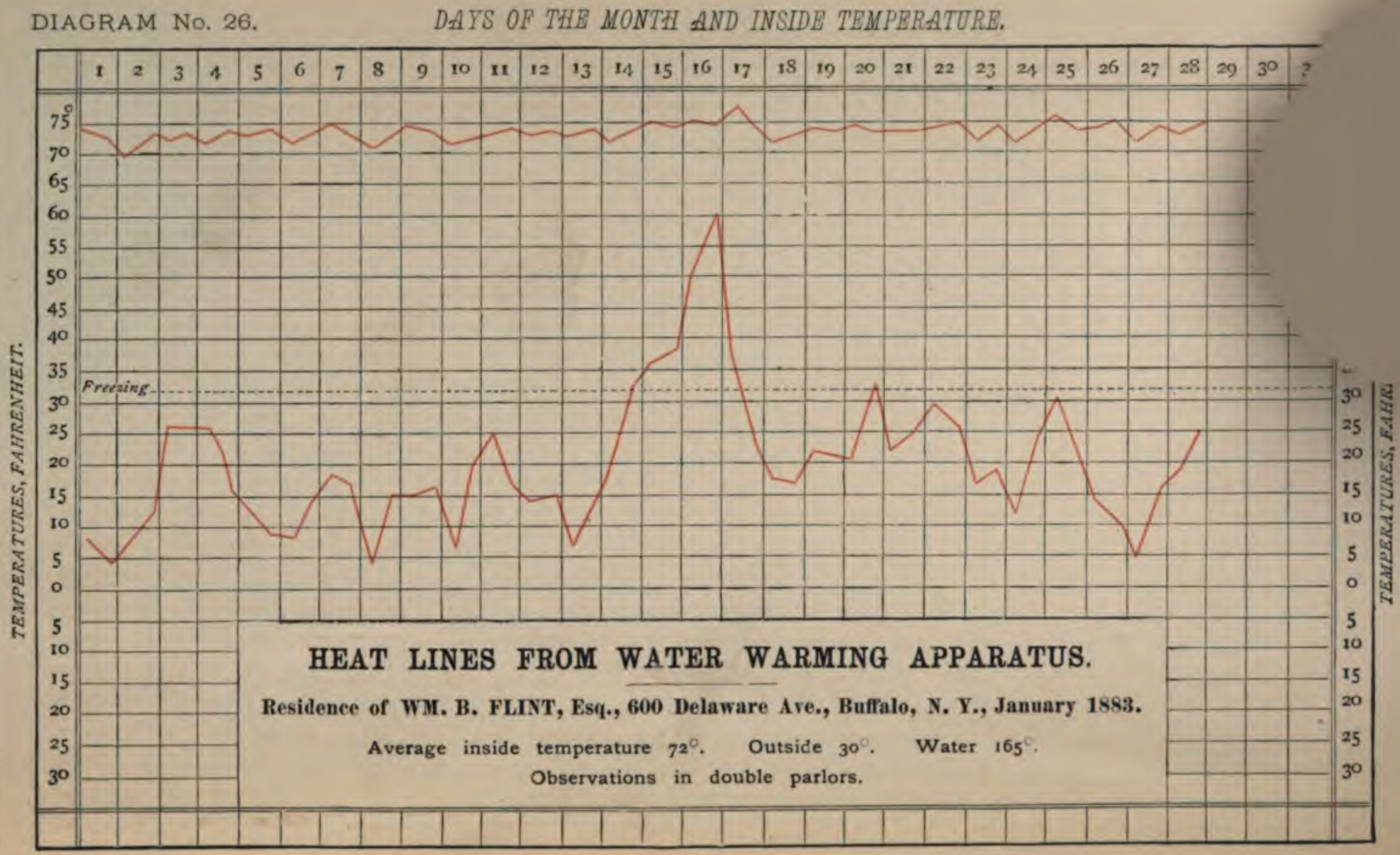
On this basis we conclude that the average dwelling, with not more than one half of the heating surface *indirect*, should be warmed 24 hours for 1 cent per 1,000 cubic feet, with fuel at $3 per ton. That is to say, rooms of 4,000 cubic feet, 24 hours, 4 cents in a good house, under the average difference of temperature stated.

That this is not often done, may be conceded; but it shows what may be realized with a large apparatus properly proportioned. In this lies all *the "law and the gospel"* of domestic heating.

We cannot go into the other diagrams as much at length, except to note that we can secure substantially the same condition in different dwellings managed by the proprietor. (Diagram No. 26.)

Diagram No. 27 shows a record of lower temperatures, the owner not desiring as much heat; and, as he was away at his store all day, the boiler was well closed down. We may also note the effect of government by *hand*.

DIAGRAM No. 26.

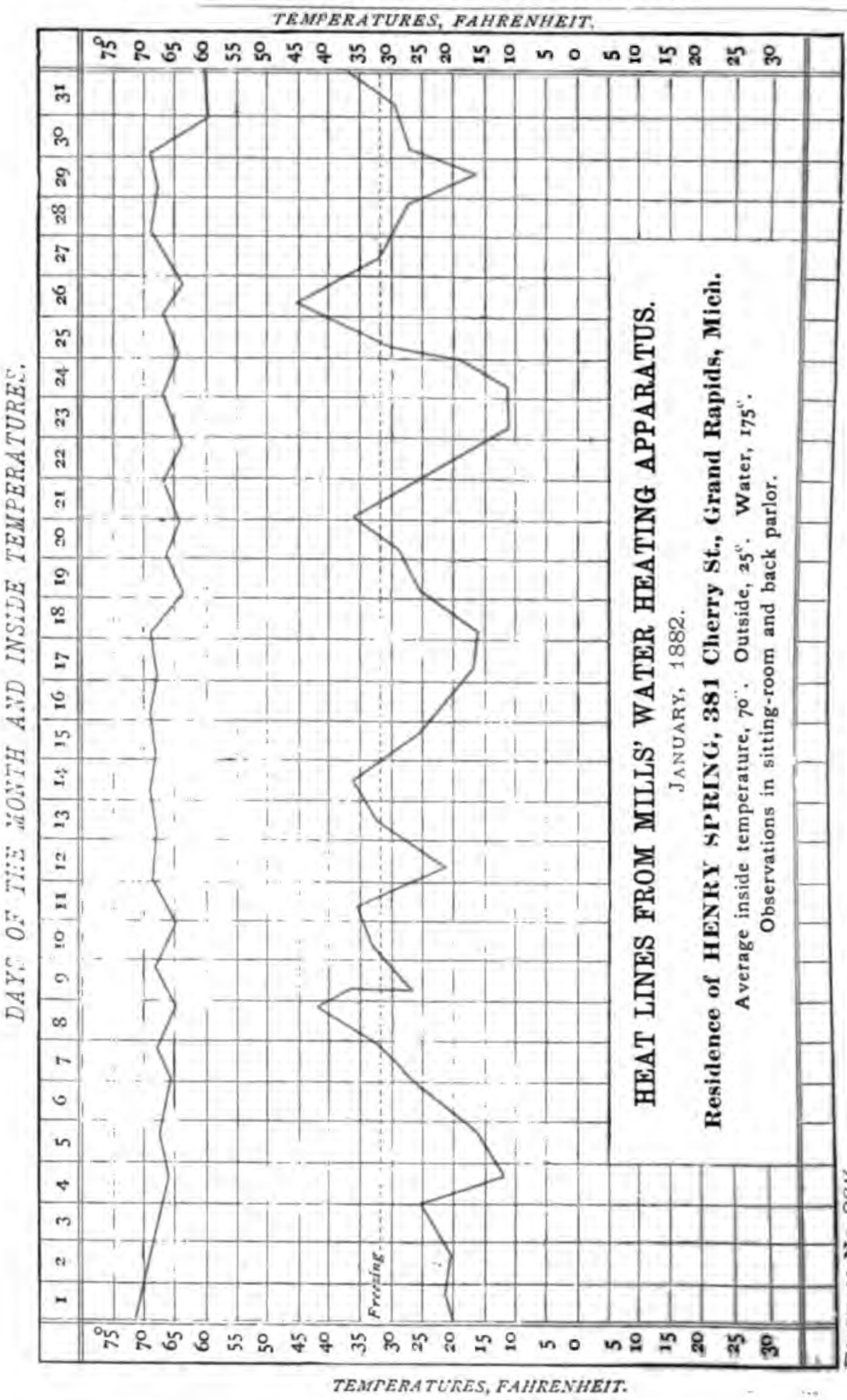


HEAT LINES FROM WATER WARMING APPARATUS.

Residence of WM. B. FLINT, Esq., 600 Delaware Ave., Buffalo, N. Y., January 1883.

Average inside temperature 72°. Outside 30°. Water 165°.

Observations in double parlors.



HEAT LINES FROM MILLS' WATER HEATING APPARATUS.

JANUARY, 1882.

Residence of HENRY SPRING, 381 Cherry St., Grand Rapids, Mich.

Average inside temperature, 70°. Outside, 25°. Water, 175°.

Observations in sitting-room and back parlor.

DIAGRAM No. 26½.

CHAPTER XXV.

GENERAL PROPORTIONS OF HEATING APPARATUS.

PIPE LINES, RADIATOR CONNECTIONS, AND MISCELLANEOUS.

IN considering the question of pipes for conveying heat in a liquid instead of a gaseous form, we do not propose to go into the matter much at length, since it has been considerably treated in the preceding chapter on methods and causes of water circulations.

That any detail of pipe construction is largely if not wholly dependent on the theory or system for the whole apparatus, is apparent, and therefore we must observe what theory has been woven into data presented as insuring certain results with either pipes or radiators.

If it has been predicted for any reason that a water apparatus shall operate only under *low pressure*, *low temperatures*, and *slow circulation*, then obviously the data found to apply to such conditions must be used in determining the size of pipe, and the amount of heating surface required to produce a given result. This data may be found in most books that have treated the open-tank and mild-water circulations of the past and present day.

The calculations will be found to relate mainly to the *hydraulic flow and friction of water*, generally under no head or pressure but that due to the weight of the water, and with small differences of temperature between the flow and the return pipes; most cases 15° to 20°, affording a head not exceeding one inch of water as the total motive power of the circulation. While such small powers are sufficient to produce a circulation in large pipes carefully graded to carry a limited amount of heating surface, they will not avail to overcome any unusual friction or loss of power in pipe or boiler.

On the other hand, if it is conceded that the boiler, pipes, and radiators may operate under any moderate pressures, the water having the same temperatures as steam, then we may conclude, without any great amount of figuring, that the sizes of the pipe that will convey the same amount of heat with steam [illegible] will convey as much with a liquid circulation of the [illegible]

This we have found to be [illegible] disposes of the great drawback, — the increas[illegible]ased cost of a water apparatus over a stea[illegible]

We have shown in plate 41, page 432, what we consider the best all-around system of piping for any building, even where there are "*indirect*" radiators located in the basement. The proper supply for them is one of these overhead return lines, as shown in figure 9; since it is plain that, under the most favorable circumstances, the ordinary supply line to a radiator *parts with less than ten per cent of its total heating capacity in any one circulation*, the rest of the heat contained in the water (minus what is lost by radiation) is returned to the boiler.

Therefore an *overhead* return line is in a fit condition to become a supply to almost any stack of "*indirect*" radiators located in the basement; where, if parting with say 20 per cent more of the heat contained, it will then only have done a fair duty, and reach the boiler minus 30 instead of 10 per cent of its heat-carrying capacity. Of course having once seen that the proper place to connect "direct" radiators is the *return* lines, we need not hesitate to supply the "*indirect*" in the same way, and obtain like valuable results.

Speaking of "indirect" and even "direct" radiators on the first floor of buildings, we remark that they are always slow to circulate, and that larger pipes are required. This, of course, is because of the small height relatively above the boiler, and thus the little power to overcome friction and move the water.

A remedy for all this uncertainty will be found (as in steam circulation) by applying the single-supply and one-pipe system *horizontally*: that is, by carrying a single line through the centre of a basement to the remotest point before branching, then dividing it by a T-fitting and long-turn elbows, and carrying two lines around on the outside of the building, and supplying all the radiators and risers, if desired, from what is then the return line.

I am not prepared to say that we could take the return water from extensive and numerous radiators as a common supply, as in our vertical system (Plate 41), but we could to a great extent; since, the cooler the return water finally becomes, the faster it will travel and return to the boiler.*

The diagram (No. 22, page No. 437) of the actual temperatures of the main flow and return lines (Pierce Building) is another proof of satisfactory work in both the radiators and the lines of supply. The summary presented of the demand for heat for the several floors, both on the steam and the water system, shows the proportion that each surface must supply. (See page 440.)

There are other questions that might be considered, but many of them will be found treated in the tables and diagrams accompanying this section.

---

* I think Mr. Baker, of the firm of Baker & Smith, New York, invented and patented a supply from, and return to, a *horizontal* pipe many years ago.

Continuing our review and references to the overhead or vertical method of water piping, we may add a few words on conditions not elsewhere treated.

We have considered in Chapter XXII. the effect of closing the domestic water apparatus, and placing it under the same conditions as the low-pressure steam apparatus; but we have said little about practical applications of this kind of piping to dwellings. This is mainly because, as far as the contractor is concerned, he will have to decide upon them for himself. It should be seen, however, that, where "direct" radiators are to be used in the rooms, the pipes not being concealed, that it makes neater and simpler work to use but one pipe instead of two, since this single pipe may be run almost anywhere (even through closets), and small connections made from it to the radiator.

One-half inch supply and return connections to radiators are all that are required; if there are but two floors, and radiators to supply, one and a quarter inch lines are ample, and such lines are then ready to serve a radiator or stack of radiators in the basement; and we may note that here is the condition to secure a good circulation through a radiator on the same level, or even below the boiler, if it should be desired; in other words, it is almost impossible to stop a circulation connected in this way.

Of the sizes of these vertical supply lines to carry heating surfaces, we may say that at the Pierce Building the vertical lines are for the *six stories two inches*, the average size of radiators (sixteen-section Union) being *seventy-two square feet*, while several of them are larger (see table, page 441); *thus we have over four hundred square feet of surface to a single supply line, which is also the return.* The connections for these radiators are one-inch pipe; but to get the proper centre an eccentric bushing was employed, reducing the openings to *one half an inch*, without in any way reducing the efficiency of the radiators.

As showing that this *overhead* and *vertical* system of water-piping is favorably regarded by practical heating men, we may refer to several parties who have tried it in both large and small buildings.

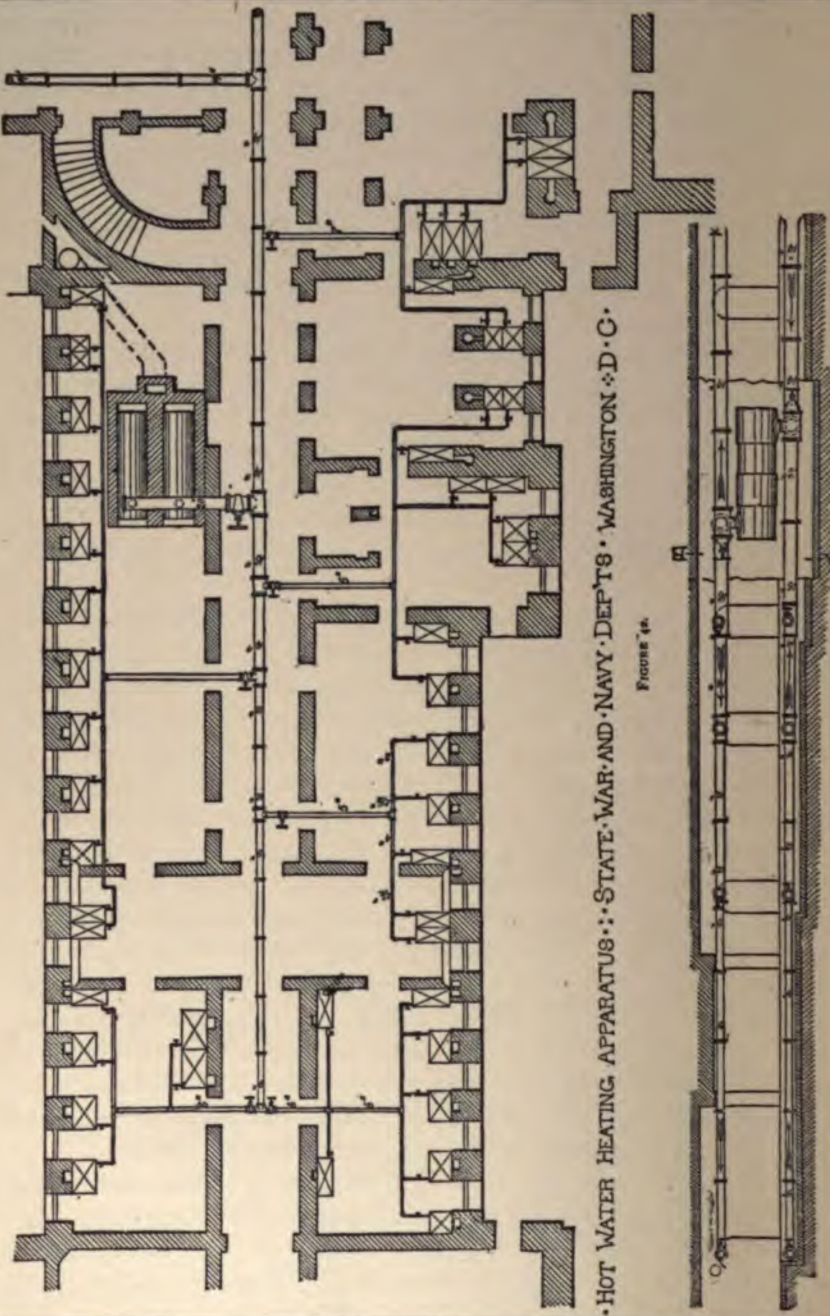
Mr. Wm. B. Allan, an intelligent and progressive architect, in St. Catharines, Ont., was one of the first to make a practical trial of the system. (See his letter in the section on ventilation.) The new and old college buildings at Worcester, have just been piped from these plans; also a block of buildings on Mount Vernon Street, Boston.

The Middlesex Machine and Heating Company, of Lowell, have also adopted the system for a large school building at Andover, Mass. It will also be put into the new Hi [illegible] l school buildings at Westfield, Mass.; A. A. Sanbo [illegible] amingham, Mass.; it is also in use at the City Ha [illegible] of M. M. H. Co.

DIAGRAM No. 27.*

SYSTEM OF WATER PIPING FOR LARGE PUBLIC BUILDINGS.

Low temperature, open tank, and for Indirect Radiators.



·HOT WATER HEATING APPARATUS·:·STATE·WAR·AND·NAVY·DEP'TS·WASHINGTON·:·D·C·

FIGURE 42.

SECTION THROUGH HALL OF WEST-WING SUB—BASEMENT

FIGURE 43.

*Plans drawn by BARTLETT & HAYWARD, Baltimore, Md.

In these two diagrams are shown two applications of the *low temperature and open-tank water system* of piping, both for direct and indirect radiation. The first, page 464, is a limited sketch of the boiler, pipes, and radiators, as arranged for the largest class of government buildings. The plans are by Bartlett & Hayward, Baltimore, and are similar to other large public buildings heated by them.

They are referred to, as showing the general arrangement and magnitude of the pipes and fittings found necessary in this class of water heating, and where the data of "hydraulic flow and friction" of water in pipes will lead the engineer who adopts them. It will be seen that the main flow pipe at the boiler is 16 inches, both supply and return, reducing to 14, 12, and 9, 6, 5, and 4 inches diameter, as the several amounts of heating surface are supplied. We may also refer to some other extensive and late water apparatus by the same firm. At the Johns Hopkins Hospital Buildings, Baltimore, the main flow and return pipe are 24 *inches diameter*, reducing as before stated. At the Boston Court House, now in course of erection, *the main flow and return pipe are* 30 *inches in diameter*, flanges 38 inches, all 1¼ inches thick, and of the best quality of gray cast iron.

To supply the water to this system of pipes, there are 12 horizontal tubular boilers, 48 inches in diameter, 16 feet long, with 72 3½-inch tubes in each. The total heating surface in coils and radiators is something over 95,000 square feet, to provide for a cubical contents of about 3,000,000 cubic feet of space, the proportion being about 1 to 33, or what would be provided for a private dwelling, and for a low temperature circulation.

For the comparative and approximate cost of such large work, we note that the new Court House (3,000,000 cubic feet) costs to heat $117,000, or $39 per 1,000 cubic feet of space warmed. The county buildings at Springfield (749,000 cubic feet) cost $16,000, *including mechanical ventilation, cooking, and laundry apparatus*, or $22 per 1,000 cubic feet.

The Pierce Building (555,000 cubic feet) cost $10,000, equal to $18 per 1,000 cubic feet of space. The Trinity Church and Chapel, double apparatus, and nearly all "*indirect*" radiation and *with mechanical ventilation* (600,000 cubic feet), cost $15,500, or $26 for each 1,000 cubic feet.

That there is a difference between these two systems of 50 per cent in *pipe areas and heating surfaces for a given and equal duty*, may seem surprising; but this certainly seems to be the case, as all the data and diagrams here inserted go to show.

This conclusion is corroborated by the conditions at the Pierce Building, where we have proof that the inferences drawn are correct; and that even a greater demand may be met and more heat supplied to radiators by one pipe than by two or more, which start at the boiler and end at the radiator.

The following diagram (No. 28) is a sketch plan and elevation of piping for the supply of direct radiators on several floors.

It was not credited in the *Building Record* to any one in particular, but may be said to fairly represent the English and Continental methods of *open-tank* water application, both for public work and for domestic heating.

It is, as we said, the general and common plan of piping for direct radiators, and is seen to consist of *separate* circulations of supply and return to the several floors, the return lines not being shown for want of room, though they may be stated to follow very closely the other lines; and thus for every line and branch, there is another line not drawn on the plans.

The small figures on and near the vertical supply lines show the sizes of the pipes, and the amounts of the heating surface that each is arranged to carry; B. C. standing for box coil, W. C. for wall coil, R. for radiator; A, B, and C being the main flow pipes to basement, second, and third floors.

This is doubtless a fair example of the *open-tank, low-temperature, multiple-pipe system* as discussed by Hood and others, and for which Mr. Baldwin has given such extensive and valuable data.

We should have been glad to have presented some of Mr. Baldwin's diagrams, illustrating the sizes of pipe which he figures out as proper and requisite to carry stated amounts of heating surface for this kind of apparatus with given losses of temperatures. But the publishers of his book, when applied to, were, as they said, doubtful about granting permission to copy matter from a *new book;* so the best we could do was to transfer water lines for certain stated amounts of heating surface to diagram No. 29, page 469, already made for a similar purpose, and to which Mr. Baldwin's steam line (B) from his former book* had already been placed. It falls, as seen, between the writer's line (C) and that of Robert Briggs's (A).

We do not claim that these water lines have been perfectly placed, as they would have been in the original, but they will be found near enough for useful comparison.

In presenting these sketches of pipe and fitting, used with an open-tank system, and the diagram of comparisons of piping, we do so, not as further criticisms upon the systems, or upon those who employ them, but as showing the main difference in the sizes, number, and cost of the pipe required to convey a given amount of heating material. Yet of the matter of the general pipe system and practice shown, we may remark that the compound or single circuit system is the result of much experiment, and, we may say, many failures to form reliable circulation from the single main or trunk line.

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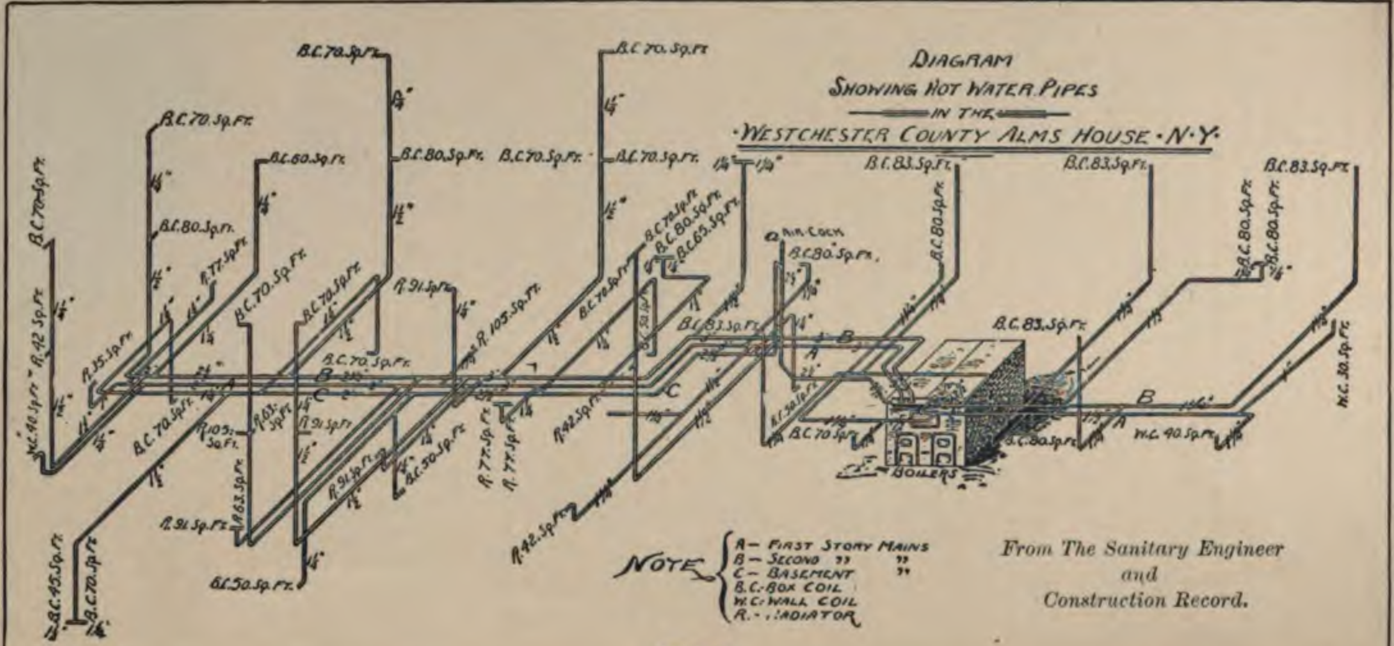
* Steam Heating for Buildings.

DIAGRAM NO. 28.

This diagram of water piping illustrates the construction of a low-temperature and open-tank system, including separate circuits for each story. (Only the supply lines are shown.)



From The Sanitary Engineer
and
Construction Record.

FIGURE 51.

Line C, basement,	2½ inches;	area, supply, 4.74 square inches;	500 square feet radiators.
" A, first story,	3 and 2½ "	" " 12.00 " "	1,120 " " "
" B, second story,	3 " 2½ "	" " 12.00 " "	1,510 " " "
Total		28.74 square inches;	3,130 square feet radiators.

EXPLANATION OF DIAGRAM NO. 29.

The different sizes of wrought-iron pipe of standard dimensions, one to ten inches internal diameter, are represented by the figures on the radial lines.

The *curves* show the sizes of main supply and return at the boiler (low-pressure steam and water) for different amounts of radiating surface, reading from the margin to the circle nearest the curve.

The length of the supply pipe from boiler to radiator varies in different apparatus, but it is of less importance in determining the size of the pipes, compared with the amount of radiating surface carried. Its average length in feet is taken in the diagram as *one-tenth the square feet of radiating surface.*

Line A is the theoretical size required for steam, according to the data of Robert Briggs' "Steam Heating" (pages 90–91), where the resistance equals six inches water column, the friction of bends and elbows, valves, etc., being considered equal to one half additional. Under these conditions the size of the internal diameter of the pipe in inches is represented by the diagram (outside line).

Line B is, according to the rule for current practice given by W. J. Baldwin for low-pressure steam-supply mains (page 124, "Steam Heating for Buildings"):

"The area of a one-inch pipe per one hundred square feet of radiating surface."

Line C is the size of *steam* or *water* supply and water return lines, according to the practice of J. H. Mills.

Line D (*Steam*), for the return of condensed water, is one-half the size of supply (B), (current practice).

Lines E, F, and G are the *theoretical* sizes of main horizontal pipes for *water circulation*, according to rules and data by "Thermus" in the *Engineering and Building Record* (August 18 and October 13, 1888).

Lines E and F are the sizes of pipe required for *direct radiators.*

Line G gives the sizes of pipe for *indirect surface.*

In the case of water circulation the sizes of the supply and return pipe are the same: by the length of the supply pipe is to be understood one-half the length of the circuit.

Examples of buildings piped according to Mills line C, for steam, are the State Insane Asylum and new Police Building at Buffalo, N. Y.

For water, the Hampton County Jail at Springfield, Mass., the Pierce Building, and Trinity Church, Copley Square, Boston, Mass. See also page 463.

REFERENCES AND CONDITIONS.

Pierce Building, six stories; cubic feet, 375,000; radiation, 5,452, or 1 to 70. See table No. 16 and diagram No. 22, page 437.

Trinity Church, Copley square, Boston, Mass. Main building about 500,000 cubic feet; radiation mostly indirect, with large cold-air supply; 5,000 square feet, or 1 foot of radiator to 100 feet of space. Size of main supply and return, 6 inches.

Eliot Church, in Newton, Mass., substantially the same data, including mechanical ventilation.

Example. For 2,000 square feet of radiating surface.—Having first found the number 2,000 in the margin, we follow the straight line leading from that point to the centre, to where it meets the colored curve C, which, it will be seen, is drawn from the centre in an eccentric line.

Just below the point where the straight line meets this curve is the 3½-inch circle, which is accordingly the nearest commercial size of pipe demanded for water or steam by the *Mills system of closed-tank water apparatus or low-pressure steam, with gravity return of the water of condensation.*

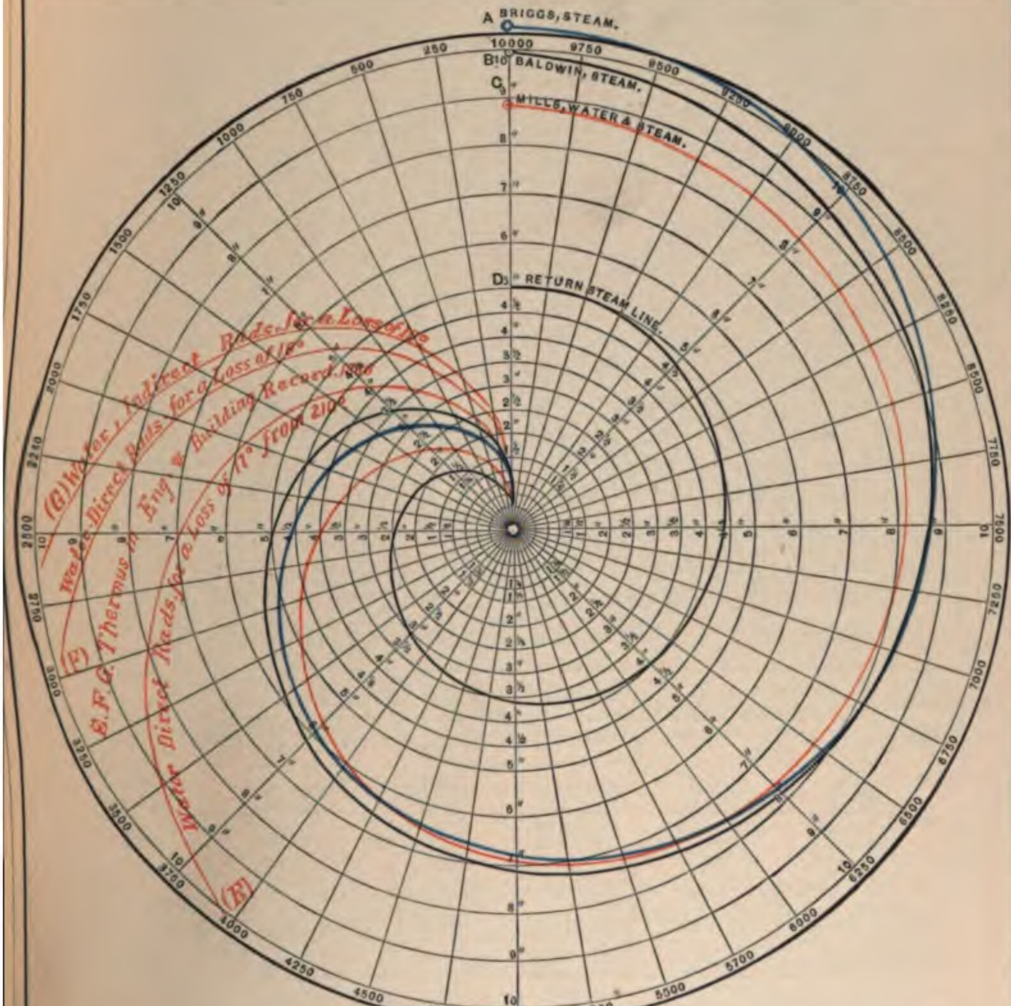
Similarly for the other curves, most of which are colored, representing other systems and conditions, *the circle nearest the point where the straight line representing the required amount of radiating surface meets the curve*, is the proper size of pipe; if the diameter of the pipe is not on the line at that particular point, but by reading on the same circle a few lines to the right or the left, it will be found.

DIAGRAM 29.

Comparison of Piping Showing the Sizes of Steam and Water Main Supply and Return Pipes, also Heating Surface at approximate distances from Boiler.

From the Data, Experiments, and Practice of

ROBERT BRIGGS, WILLIAM J. BALDWIN (THERMUS), AND JOHN H. MILLS.



The figures on the *outside* circle show the square feet of heating surface which may be carried by the indicated sizes of pipes.

Pointing off one figure gives, *approximately*, the *distance* in feet these surfaces can be carried from the boiler.

The small figures on the radial lines indicate the diameters of pipes required for the amounts of heating surface by the respective Engineers.

TABLE No. 18¼.

HEAT EMITTED BY STEAM AND HOT WATER PIPES AT DIFFERENT TEMPERATURES AND DIFFERENTLY EXPOSED TO COOLING INFLUENCES.

THOS. BOX.

PIPES FREELY EXPOSED TO AIR AT 60 DEGREES AND WALLS AT 60 DEGREES.

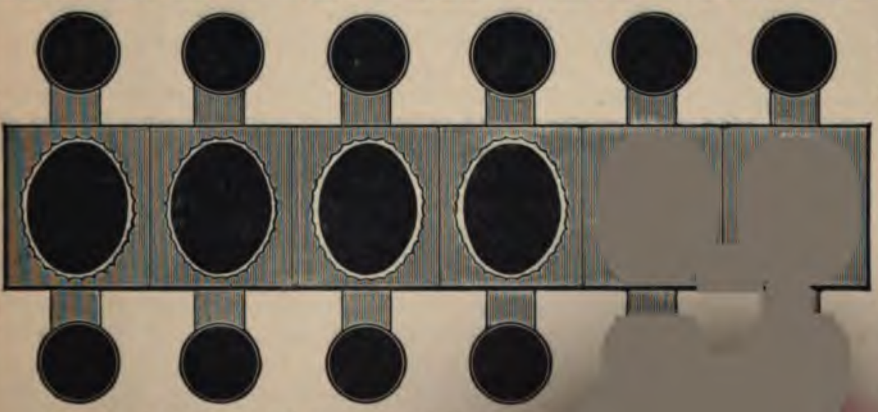
Mean temp. of the pipe.	Temp. of the air.	Difference.	Units of heat per square foot of surface per hour.		Units of heat per foot run of pipe per hour.		Lbs. of air heated 1° per foot run pipe, per hour.		Cubic ft. air at 60° heated 1° per foot run.	
			2″	3″	2″	3″	2″	3″	2″	3″
300°	60°	240°	619	574	403	545	1693	2290	22235	28713
280	60	220	543	505	355	480	1491	2017	19582	26490
260	60	200	477	443	312	421	1311	1769	17218	23233
240	60	180	414	385	271	366	1138	1538	14946	20199
220	60	160	356	330	233	313	979	1315	12858	17271
210	60	150	327	303	214	287	900	1206	11826	15847
200	60	140	299	277	195	263	820	1105	10775	14507
190	60	130	271	251	177	239	744	1004	9777	13193
180	60	120	245	227	160	216	672	907	8830	11920
170	60	110	220	204	144	194	605	815	7950	10710
160	60	100	196	181	128	172	538	722	7070	9487
150	60	90	172	159	112	151	470	634	6176	8331

Cubic Feet of Air (at the Temperature of the Room) Heated from the External Temperatures per hour, per foot run of Steam Pipes, Heated to 210° and Exposed to Air, &c., having the Temperature of the Heated Room.

Temperature of the External Air.	TEMPERATURE OF AIR IN THE ROOM.						
	42°	52°	62°	72°	82°	92°	102°
	CUBIC FEET OF AIR BY 2-INCH PIPE.						
12°	451	302	225	186	151	124	102
22	626	403	281	223	176	141	115
32	1253	604	375	279	211	165	131
42	. .	1208	513	372	264	198	153
52	. .	. .	1126	557	352	247	184
	CUBIC FEET OF AIR BY 3-INCH PIPE.						
12°	560	406	313	250	204	168	138
22	840	502	391	300	238	192	156
32	1680	813	521	375	285	224	178
42	. .	1626	782	500	354	268	208
52	. .	. .	1563	750	475	335	250

NOTE.—To bring these tables to *standard radiator conditions*, deduct 20 per cent.

ROYAL UNION RADIATOR.*



For full list of experiments, see tables 10 and 11.

For action of heat rays, see diagrams 17 and 18.

*THE H. B. SMITH CO., WE [illegible]

PRESSURE, TEMPERATURE AND EFFICIENCY OF RADIATORS. WATER SYSTEM, SINGLE LINES.

EXPLANATION OF FIGURE 23 AND TABLE 15.

Figure No. 23 illustrates a portion of a series of experiments made by the author in the winter of 1881. This was on a *model* apparatus constructed in the building of the Grand Rapids & Indiana Railroad, to ascertain facts relating to the working of water under the same condition of piping as the steam system of the writer, patented 1874 and 1875. The building referred to was being fitted for a steam circulation of the same construction, so that there were both apparatus and systems under heat at the same time. Some very significant results were reached, and formed the basis of many other water circulations in the same line. School No. 7 in the same city was treated in this way, and many more valuable facts and data secured. The final results are not shown here, but they are similar to those seen in diagram No. 23 for the new schoolhouse in Buffalo, 1886, where the writer operated in the years from 1883 to 1887.

This cut shows the method of piping and connection to radiators on the Mills overhead system for water and steam (illustrated on page 432), and in operation at the Pierce Building, Copley Square, Boston, Mass. See frontispiece, also description of the piping in that building, pages 434, 435. See also water experiments, page 477.

Referring to table No. 15, it will be seen that only records of the higher temperatures (200° to 300°) are noted, the others not being saved or considered important for this illustration.

All the other conditions of temperatures are noted on the table from the time the water leaves the boiler, and are then taken, as seen, from the attic, where the expansion tank was located, *down* through the *third*, *second*, and *first floors* to *basement*, where the circulation re-enters the boiler.

The radiator thus abstracted 15° in one passage of the water; the duty of such surface being (table No. 19) 200 units per square foot, or 30 x 200 = 6,000 units for the whole radiator; this ÷ 15 (number of degrees cooled) = 400 pounds of water passed through the radiator per hour, requiring a velocity of 400 ÷ 19.6 = 20 feet per minute in the 1-inch supply pipe, and nearly the same velocity in the 1½-inch riser above and below the radiator. See also experiments with water radiators, page 477.

As bearing on the question of the pressures which would result in a closed apparatus with increased temperatures, we may examine the lower three lines, and conditions taken March 7 and 8, and covering the *excessive* ranges of 240° to 300°.

First we see that the head due to the height of the unheated columns was 24 pounds, and that in passing from 212° to 240° we raised our pressure to 35 pounds, or an increase of 11 pounds only, and that in passing from 240° to 300° we raised the pressures only a corresponding amount, or increase of 4 pounds pressure for each 6° raised. Thus the additional pressure in the boiler above that due to head of water was the same nearly as the pressure of steam in the tank. See table No. 14.

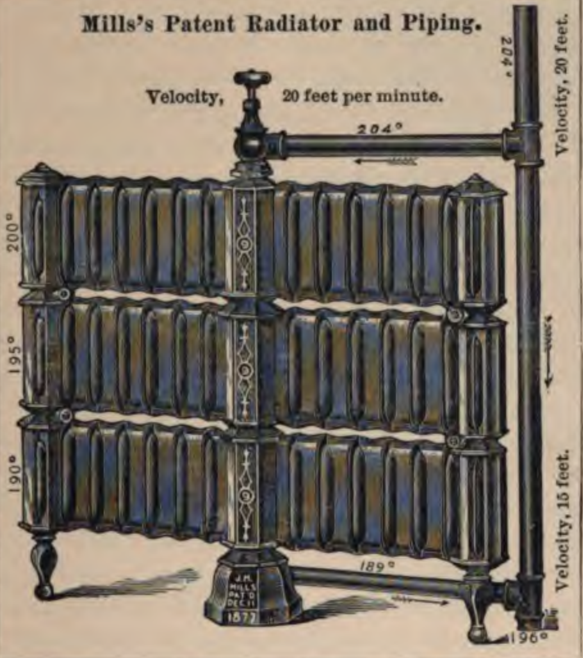
As a matter of fact, these are doubtless the extremes of the pressures likely to occur in a high temperature apparatus, since they are attained only when we heat the water from a temperature of 40° to the several higher points noted, and without allowing any of the compressed air to escape; but, as the water is in general raised from 40° to the working temperature but *once in a season*, we really have no such ranges of expansion to deal with, the whole range of variation being *less than one hundred degrees*. See diagram No. 22.

NOTE.—From the result of all experiments on steam and water radiators, we conclude that the temperature shown in table No. 18½ will yield 300 units of heat per foot of radiator per hour.

FIGURE No. 23.

EXPERIMENTS AT GRAND RAPIDS, MICH., FEBRUARY, 1881.

Circulating Water in Single Lines of Piping, the Arrangement on Three Floors being the same as shown.



Mills's Patent Radiator and Piping.

The Water was conducted directly to Tank in Attic,

Circulation being DOWNWARDS.

See also plate No. 45, page 467.

	Temperatures.					Attic.	Third Floor.			Second Floor.			First Floor.		
Date 1883.	Outside.	Inside.	Supply Pipe.	Return Pipe.	Difference.	Expansion Tank.	Supply to Radiator.	Return.	Difference.	Supply to Radiator.	Return.	Difference.	Supply to Radiator.	Return.	Difference.
Feb. 27	60°	68°	220°	185°	35°	210°	200°	190°	10°	198°	180°	18°	188°	175°	13°
22	45	65	230	183	47	215	206	190	16	200	180	20	190	176	14
23	50	58	214	180	34	203	198	185	13	193	176	17	186	173	13
24	40	60	225	189	36	215	206	190	16	199	183	16	190	177	13
25	30	65	220	178	42	215	208	190	18	195	173	22	180	170	18
26	28	70	250	201	49	230	220	201	19	210	200	10	208	190	18
28	25	68	225	200	25	225	215	200	15	212	203	9	206	184	22
28	20	65	250	204	46	230	220	204	16	206	190	16	208	194	14
Mar. 1	30	68	225	208	17	212	210	194	16	206	190	16	200	184	16
2	30	70	230	188	42	220	212	193	19	210	188	22	203	180	23
Aver'ge	35.8	65.7	229	192	37	218	210	194	16	203	186	17	196	178	16
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O

OBSERVATIONS OF BOILER, MARCH 7 AND 8.

Head 55 Feet.	Degs. Fah.	240°	245°	250°	255°	264°	270°	280°	285°	288°	290°	295°	300°
Natural Pres-	Lbs. pr sq. in.	35	38	41	43	45	50	53	55	58	60	65	70
sure, 24 Lbs.	Increase.	11	14	17	19	21	26	29	31	34	36	41	46

See experiments with water radiators, pages 474, 475.

WATER RADIATORS.

While the supply of any heating surface is more or less connected with the plan of piping adopted, it relates more to the kind of the radiators than to anything else. If the radiating surfaces are lines of pipe or horizontal sections, as in the Whittier or Mills radiators, there is no choice as to where the water can be admitted, since the circulation is horizontal backwards and forwards through the lines or bars from the highest to the lowest; and the water must be admitted to the highest coil or bar first in order to move at all.

In vertical tube radiators, now more commonly employed, the circulation or movement of the heated fluid is also of necessity vertical; that is, from the highest to the lowest point of the tubes.

At whatever point the heated water is introduced to a vertical tube radiator, it immediately takes the nearest and largest tube, and moves in that to the top, where, finding the horizontal cross connection or manifold header, it heats this, first passing horizontally to the farthest end, displacing as much of the cold water, and putting the whole body of water in motion out of the radiator *downward*.

The top horizontal cross tube then becomes the supply to all other vertical tubes, be it one or one hundred, and they are all supplied *simultaneously downward at a uniformly even rate*, expelling all the cold fluid, at once being replaced by the hotter current, establishing the only *natural and possible* movement of the two bodies of water, one of which is many degrees hotter at first, and always maintaining 10° to 15° difference between the inlet and outlet water.

It should be seen that the velocity of such a circulation is dependent on the amount of cooling within the pipe or tubes of the radiator. The greater the cooling and the difference between the supply water and that of the radiator, the quicker the circulation, and, other things being equal, the greater the amount of heat dispensed.

Some persons have supposed that the amount of water in circulation had much to do with the efficiency of both boilers and radiators. We do not share these opinions, only as far as the water is brought in direct contact either with the heating or cooling surfaces; yet the amount of water in the boiler or piping would influence the question of *time*, both in heating and cooling.

As far as the radiators are concerned, there is but little difference in the amount of water held in the pipes of different constructions. This is seen in the sections of the Union, Triumph and Gurney radiators and in diagrams 17 (page 336) and 18 (page 352). Probably wrought-iron pipes have the greatest internal area to outside surfaces, but it has not been found easy to work these wrought tubes into a vertical radiator for water. We have given one example in plate No. 25. See page 319.

Resuming our consideration of the circulation of a heated current in radiators, we may plainly see that it makes no real difference, after the radiator is once in circulation, where the heated current is supplied, top, bottom, or side; the current will be established *from the highest point of the vertical tubes to the lowest*, the velocity being affected only by two things—the form and grouping of the tubes and the temperature of the air and surrounding walls.

Still, if we can enter the top of a water radiator at once, it will save both pipe and fittings, also two right-angle valve turns in the current. When our supply comes from above, as it always should, we arrive at the top of the radiator first, and have nothing to do but enter; if for any reason we are below, and the radiator is tapped at the top, we may run past the end and enter as before; but there is no real necessity for doing so, as the water will take the first upright tube to the top.

In figure No. 23, actual conditions, we note that the inlet water was at 204°; after passing the first bar of the radiator 200°, the second bar 195°, the third bar 190°, and in the outlet pipe 189°, being a loss of 15° *in the radiator (or 7½ per cent). After reunion in the pipe*, 196°, *loss only* 5 *per cent*. As there were 30 feet of surface in the 3 bars, there was surrendered *one half a degree per foot for each circulation*, or passage of the water through the radiator; and from this and other data we see that the circulation, the filling and emptying of the radiator, took place 7 to 9 times per hour, varying with the temperature of the room and that of the supply water. See page 473.

We had in these experiments 30 feet of surface, cooling 400 pounds of water a less number of degrees; or 1 foot of surface cooled 12 pounds of water 17°, and thus 60 pounds of water passed 7 times through the radiator per hour, surrendering 200 units of heat, which is all that we can extract from a foot of radiating surface per hour for water at 200°, and air at 70°.

Comparing this with our other experiments with the Union radiator (page 477), we see it amounts to about the same thing; i. e. a larger amount of water cooled a less number of degrees.

Referring to the always important matter of piping and to the efficiency of a single line, it appears by the above and many other experiments that no amount of supply and return lines can increase the work of the radiators by a single degree. The one pipe line (Figure No. 23 and Plate 41) will give the radiator the supply of water it wants, and take from it all the water it can discharge after cooling, while still keeping in condition to handle many more radiators on successively lower floors; since a 1½-inch line, feeding 30 square feet of surface, or a 2-inch line, feeding 60 feet of surface, *surrenders only about* 5 *per cent of its available heat to any one radiator of* 40 *to* 50 *square feet from a supply pipe of* 200°. *If the pipe was* 300°, *the loss would be only* 3 *per cent.*

TESTING WATER RADIATORS, DIRECT AND INDIRECT.

In a recent treatise on water heating (1889), a writer proposed a method of testing radiators which has some advantages over cruder tests sometimes employed where the temperature of the air is taken as representing the duty of the surface.

This method as described consists in filling the radiator with water heated, and noting the fall of temperature in a limited period of time while the surface is cooling. In computing the heat surrendered it is necessary to ascertain the weight of metal and that of the water in the radiator; then taking account of the specific heat of the iron and the fall of temperature of both the metal and the water, the value of the heat with which the radiator has parted during the interval is computed.

While the above may be in general sufficiently accurate, it is to be noticed that the conditions are not precisely the same between water *standing* in the radiator to cool and where it is *flowing through*, and is thus continuously agitated, as in cases in practice where there is a water circulation in and out of the radiator.

A simple method employed by the writer is shown by the following report of experiments with the Union radiator June, 1888.

This requires no account to be taken of the *weight of the iron or its specific heat;* the conditions of the test are nearly the same as when the radiator is in use, the latter being set in position and *the water allowed to flow through it;* the test can be continued any length of time without change of conditions or temperatures.

In the experiments noted, the radiator was connected with a hot-water supply tank near the boiler. Instead of the ordinary return pipe, a pet-cock was inserted at the base of the radiator, and the water drawn off at a uniform rate and weighed on scales, thus reproducing the condition of the radiator when in actual use. It will be readily seen that the weight of water flowed, multiplied by the difference between the temperature of the water entering the radiator and that flowing out, is the whole number of units of heat transmitted.

In order to measure the temperatures, thermometers were placed in the pipe leading into the radiator, and in the short pipe connected with the discharge.

In commencing the test the water was allowed to run until a uniform difference of temperature was established.

When the pet-cock was set for a given rate of flow, the temperatures remained constant throughout the test that was continued for an hour.

In the first test, with a velocity of about 20 feet per minute in the 1-inch pipe (corresponding to a discharge of ¾ of a gallon per minute), the water was cooled 22°; while in the third test, where the velocity was 56 feet (discharge 2½ gallons per minute), or 3 times as great as in the first test, the cooling was ⅓ as great, or 8°; the heat was nearly the same, the small excess in the latter case (200.5 over 200 units) being caused by the mean temperature of the water being 5.5° higher.

Another point is shown by this method of testing; namely, the velocity of the flow for a given fall of temperature; thus, having ascertained the amount of the cooling, 15° say, by adjusting the pet-cock so that this difference of temperature is shown, we find the rate that the water is moved under conditions in practice.

As is shown in table No. 19½, for the case of pipes, the total heat given out increases as the temperatures are raised, but the heat per degree difference between the water and air is more nearly uniform, and is used to determine the final result.

AVERAGE CONDITIONS AND RESULTS.

If the mean temperature of the water is 190° and the difference of the water and the air is 112°, 10 pounds of water will pass per foot per hour, and the heat abstracted will be 200 units, or 10 per cent for 40 square feet of radiator; but the heat surrendered by the supply pipe is only 5 per cent at any one point.

TABLE No. 19½.

EXPERIMENTS MADE WITH A UNION WATER-RADIATOR, 1888,

*(40½ SQUARE FEET OF SURFACE.)

To Determine the Circulation of Water in Radiators and the Heat Abstracted from the Supply Line at any point per sq. ft. of Radiator.

ENGINEERS, L. R. GREENE AND J. H. MILLS.

The water was drawn off continuously and weighed. Temperatures observed by thermometers in the inlet and exit pipes, diameter one inch.

1st—May 15, 1888. Duration of test, 1 hour.

Temperature of air of the room	80 °
“ “ entering water	200 °
“ “ exit water	178 °
Difference in temperature entering and exit water	22 °
“ “ “ air and water 189°—80°	109 °
Water (80 lbs.) passed through 4½ times per hour =	367.4
Velocity of water in pipe (feet per minute), 367.4 ÷ 19.6	18.7
Units of heat per degree difference water and air, 189 ÷ 109	1.73
Units of heat per foot surface, per hour, 22 x 367.4 ÷ 40.5 = 200 or 11 per cent	200

2d—May 18, 1888. Duration of test, 1 hour.

Temperature of the air of the room, Fahr.	75 °
“ “ “ water: Inlet 201°, outlet 183.5°; mean	192 °
Water (80 lbs.) passed through six times per hour =	470.5
Difference temperature inlet and outlet	17.5 °
Velocity of water in pipe (feet per minute), 470.5 ÷ 19.6	24
Units of heat per degree difference water and air, 192 ÷ 117	1.64
Units of heat per foot per hour, 470.5 x 17.5 ÷ 40.5 = 203 or 9 per cent	203

3d—May 18, 1888. Duration of test, 1 hour.

Temperature of the air in the room	75 °
“ “ water: Inlet 205.5°, outlet 197.5°; mean	201 °
Difference temperature of air and water	126 °
Difference temperature entering and exit water	8 °
Water (80 lbs.) passed through 13¾ times per hour =	1,101
Velocity of water in pipe (feet per minute), 1,101 ÷ 19.6	56
Units of heat per degree difference water and air, 201 ÷ 126	1.60
Units of heat per foot per hour, 1,101 x 8 ÷ 40.5 = 218 or 4 per cent	218

*WATER CONTAINED IN UNION RADIATORS.

One 37-inch section, 4½ square feet, 8 lbs. of water.
“ 29 “ “ 3½ “ “ 6 “ “ “
“ 21 “ “ 2½ “ “ 4½ “ “ “
Average, 18.5 ÷ 10.5 = 1.76, or 1¾ lbs. per square foot radiator.

At 8.35 lbs. to the gallon, 1.76 ÷ 8.35 = .21 gallons per sq. ft.

One section of the Union radiator (see diagram No. 18) consists of three pipes, one elliptical, 2½ x 2 inch, and two circular pipes. Total area, 5.92 inches.

For sectional cut of the radiator, see page 471.

NOTES.—If the air of the rooms had been at 70° instead of 80°, and the water 240°, the work of the radiator would have been 30 *per cent additional*. See tables Nos. 10 and 11, pages 223, 235.

REMARK.—The number 19.6, the divisor in the above lines, is the number of pounds of water discharged by 1-inch pipe when the velocity is 1 foot per minute.

AMOUNT OF HEATING SURFACE REQUIRED.

The tables (pages 480, 481) were prepared to save computations, but, at the same time, take account of some of the principal factors in the demand for heat, — the *glass*, the *outside wall*, and the *ventilation*.

In determining the amount of radiating surface necessary to properly warm a room, the *cubical contents* of the room play a small part, as compared to the exposure of the building as represented by the amount of outside *wall* and the *glass* in the windows, that by its material and *thinness* is continually dispersing heat, and, finally, the mode of ventilation, or the conveyance of heat from the room by currents of air.

They are generally applicable where the climate is similar to that of the larger cities of the Northern States, and will be sufficiently accurate for many localities where the difference is not great from these cities. For extreme latitudes, table, page 479, gives the correction that should be applied. See the last column, headed "Relative demand for radiators."

It will be seen that table No. 20 is for the wall and glass alone; the correction to be added for *space* is combined with this in the second table, No. 21, and the colored lines serve to show the proportion of the radiating surface, thus obtained, to the cubical contents of the room.

For sizes of buildings and rooms, not included, the general rule may be applied by which this table is computed; namely, *one square foot of radiating surface for each two square feet of glass, for each twenty square feet of outside wall, and for every two hundred cubic feet of space.*

The estimate of the cooling effect of the glass is that obtained from the experiments of Hood, and is adopted by Baldwin, Rafter, and others. A smaller estimate is made by Box for still air; but as the air is seldom still, and as the effect of wind greatly increases the cooling, as shown in preceding experiments on radiating surfaces, we have adopted the larger estimate, as more in accordance with extreme conditions, for which there must be provision.

The cooling effect of the exposed surface of the walls of a building will vary considerably with the material and thickness. When lathed and plastered inside, it may be roughly assumed to be one tenth that due to the same area of glass.

After having made allowance for the loss of heat through walls and glass, there still remains to be considered the heat required to provide for losses by the continual reception of cold air by opening of doors and leakage through crevices and the porous material of which the house is constructed.

To provide for these losses, and at the same time to make some allowance for the contents of the room, an addition has been made to the heating surface of an amount sufficient to raise the temperature of all the air in the room once every hour from an outside temperature of 32° to the standard inside temperature of 70°.

Where rooms are used for special purposes, or require large amount of ventilation on account of the number of persons present, or the uses to which the room is put, the above estimates will require modification; also the nature of the heating surface will be a factor. Thus, for example, if the room is warmed entirely by indirect radiators with a forced current of air, more heat will be due to a given surface; and the above, which is made up on the basis of a uniform duty, will no longer apply.

The following estimate of the proportion of heating surface to space warmed is taken from Hood for different buildings heated by water. While it is considerably lower than the amount usually employed in American practice, being adapted to the English climate, it serves to show the comparative differences between buildings used for different purposes: —

"Churches, one square foot of surface to from 80 to 160 cubic feet of space, according to the degree of ventilation. Dwelling-houses, 1 to 70. Halls, shops, and waiting-rooms, 1 to 80. Workshops and manufactories, 1 to 100 or 140. Schools, lecture-rooms, 1 to 120 or 140. Greenhouses, 1 to 24."

MINIMUM AND MEAN TEMPERATURE OF EACH MONTH FOR CITIES OF THE UNITED STATES AND CANADA.

COMPILED FROM OBSERVATIONS OF THE SIGNAL SERVICE, U. S. A.

Stations.	Minimum and Mean Temperatures of Each Month.																								Number of months fire is required.	Mean temperature of winter months.	Max. n'mb'r degrees temp. to be raised.	Relative demand for radiators.
	Jan.		Feb.		March.		April.		May.		June.		July.		Aug.		Sept.		Oct.		Nov.		Dec.					
	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.	Min.	Mean.				
Albany, N. Y. . . .	—16	24	—18	25	—4	35	13	47	29	60	40	68	48	72	45	70	33	61	23	49	—10	39	—17	28	7	26	87	100
Baltimore, Md. . .	—2	31	3	32	9	39	23	52	34	61	49	71	59	75	52	75	40	67	30	55	16	44	1	34	6	32	72	90
Boston, Mass. . . .	—3	27	—5	28	2	36	11	46	32	57	44	66	46	72	50	69	35	62	26	51	—2	40	—11	30	7	28	81	100
Buffalo, N. Y. . . .	—5	28	—13	28	3	30	13	34	29	52	41	64	47	69	46	68	21	65	25	48	2	31	—6	30	8	29	83	100
Burlington, Vt. . .	—16	20	—20	20	1	31	10	42	30	55	43	65	47	70	45	68	32	60	22	48	—10	36	—18	24	7	21	90	110
Chicago, Ills. . . .	—20	24	—13	25	5	32	17	46	27	56	40	63	50	71	52	68	37	60	25	48	0	38	—14	29	7	25	90	110
Charleston, S. C. .	26	52	28	52	28	60	39	68	47	71	60	81	67	79	63	79	57	76	39	64	28	55	23	51	3	52	47	60
Cincinnati, O. . . .	—7	33	—1	34	13	43	18	54	36	64	49	71	60	76	55	74	41	66	27	53	6	42	—6	34	7	34	77	100
Cleveland, O. . . .	—13	33	—11	33	0	37	15	39	28	60	42	70	50	72	46	70	38	67	26	51	8	37	—5	37	7	34	83	100
Detroit, Mich. . . .	—15	27	—20	27	—2	35	8	46	29	56	38	66	50	70	45	67	35	60	22	48	4	38	—9	27	7	27	90	110
Duluth, Minn. . . .	—38	13	—34	16	—26	24	3	33	26	50	36	58	46	68	45	64	34	59	21	43	—29	24	—30	20	8	16	108	130
Indianapolis, Ind. .	—18	36	—8	36	9	42	19	46	31	66	45	77	54	78	48	76	35	70	25	51	—2	37	—15	37	7	36	88	100
Leavenworth, Kan.	—20	28	—9	29	2	40	20	49	31	67	37	77	54	83	55	81	37	67	19	57	3	42	—4	32	6	30	90	100
Louisville, Ky. . .	—10	37	0	39	16	46	21	49	36	68	49	81	58	81	56	79	42	72	28	54	10	41	—5	39	6	38	80	110
Memphis, Tenn. . .	2	45	13	45	18	53	35	55	44	72	55	81	62	83	63	83	44	73	30	56	25	49	3	44	5	45	68	70
Milwaukee, Wis. .	—25	25	—22	29	—3	35	12	41	25	51	40	65	50	70	42	67	32	61	23	51	—14	38	—19	23	8	26	95	110
New York, N. Y. .	—6	30	—1	30	8	38	20	49	34	59	49	68	57	75	53	73	42	66	31	54	7	43	—2	33	7	31	76	100
Philadelphia, Pa. .	—5	32	—1	33	9	42	21	51	36	59	49	69	60	73	55	71	45	64	31	51	8	41	4	33	7	33	75	100
Pittsburg, Pa. . . .	—12	29	—10	31	2	39	14	50	27	61	43	69	52	73	49	71	36	64	28	51	8	40	—6	31	7	30	82	100
Portland, Me. . . .	—7	20	—7	21	1	30	14	40	34	50	42	59	51	66	48	65	37	57	28	46	—6	35	—12	24	8	22	82	110
Portland, Or.	3	43	24	44	31	45	28	54	36	60	39	60	46	68	43	65	39	61	32	50	27	47	17	37	6	41	67	80
San Francisco, Cal.	36	49	41	51	41	51	40	55	45	58	48	59	49	59	50	59	50	61	49	59	44	57	39	51	4	50	34	60
St. Louis, Mo. . . .	—16	33	—3	35	8	44	22	58	32	66	48	74	57	78	55	76	40	69	25	55	11	41	—5	34	5	34	86	100
St. Paul, Minn. . .	—30	14	—32	14	—15	24	7	37	24	62	39	69	46	75	43	70	30	61	21	41	24	26	—27	19	7	16	102	130
Washington, D. C.	—3	34	—2	37	12	45	22	56	33	66	46	74	58	78	50	76	40	68	26	58	16	45	3	37	5	36	73	90
Wilmington, N. C.	17	50	15	48	22	57	28	63	38	70	53	80	63	79	56	77	50	74	32	61	28	52	15	49	4	49	55	70
Halifax, N. S. . . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	7	25	80	100
Montreal, P. Q. . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	21	91	110
Toronto, Ont. . . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	27	82	110
Chatham, N. B. . .	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	8	15	94	130

TABLE No. 20.

Heating Surfaces Required in Radiators, Low Pressure Steam and Water Circulation, at Similar Temperatures and Average Conditions.

One square foot of heating surface = 2 square feet of glass, 20 square feet of wall, and 200 cubic feet of space.

Class	Outside Wall, Hundreds of Square Feet.																			
Sq.Ft.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
10	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105
20	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110
30	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115
40	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
50	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125
60	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130
70	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135
80	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140
90	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145
100	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150
110	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155
120	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160
130	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165
140	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170
150	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175
160	85	90	95	100	•105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180
170	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185
180	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190
190	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195
200	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200
210	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205
220	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210
230	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215
240	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220
250	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225
260	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230
270	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235
280	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240
290	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245
300	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250
310	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255
320	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260
330	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265
340	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270
350	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275
360	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280
370	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285
380	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290
390	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295
400	205	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300
410	210	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305
420	215	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305	
430	220	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305		
440	225	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305			
450	230	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305				
460	235	240	245	250	255	260	265	270	275	280	285	290	295	300	305					
470	240	245	250	255	260	265	270	275	280	285	290	295	300	305						
480	245	250	255	260	265	270	275	280	285	290	295	300	305							
490	250	255	260	265	270	275	280	285	290	295	300	305								
500	255	260	265	270	275	280	285	290	295	300	305									
510	260	265	270	275	280	285	290	295	300	305										
520	265	270	275	280	285	290	295	300	305											
530	270	275	280	285	290	295	300	305												
540	275	280	285	290	295	300	305													
550	280	285	290	295	300	305														
560	285	290	295	300	305															
570	290	295	300	305																
580	295	300	305																	
590	300	305																		
600	305																			

RULE.

Take the number corresponding to the amount of glass and outside wall (Table 20). The number opposite this (Table 21) in the column denoting the cubical contents of the room is the *radiating surface in square feet.*

Example I. Corner room 30 × 30 × 11 = 9900 cubic feet. Two exposed sides, 500 square feet of wall, 160 square feet of glass. Demand for glass and wall (Table 20) = 105*. Radiating surface (Table 21) = 155†. Proportion of radiating surface to space warmed (Table 21 = 1 : 65.‡

Example II. Room with *one exposed side*. Contents, 5000 cubic feet: 200 square feet of exposed wall; 50 square feet of glass. Demand for wall and glass (Table 20) = 35. Radiating surface (Table 21) = 60 square feet. Proportion of radiating surface to space warmed (Table 21) = (approximately) 1 : 85.

TABLE No. 21.

Combined Demand in Radiators for Rooms and Offices with Different Exposures. *

Glass and Wall from Table No. 20. Space Warmed, Air to change each hour, Table No. 21.

Based on steam conditions and pressures 5 to 10 lbs.

Radiation Required by Table 20.	THOUSANDS OF CUBIC FEET IN THE ROOMS.																		Radiating Surface to Space Warmed.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	
15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	1:170
20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	1:160
25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	1:150
30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	
35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	1:140
40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	
45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	1:130
50	...	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	
55	...	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	1:120
60	...	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	
65	...	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	1:115
70	...	80	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	1:110
75	...	85	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	
80	...	90	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	1:105
85	...	95	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	1:100
90	...	100	105	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	
95	...	...	110	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	1:95
100	...	...	115	120	125	130	135	140	145	150	155	160	165	170	175	180	185	190	
105	...	...	120	125	130	135	140	145	150	†155	160	165	170	175	180	185	190	195	1:90
110	...	...	125	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	
115	...	...	130	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	1:85
120	...	...	135	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	
125	...	...	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	
130	...	...	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	1:80
135	...	...	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	
140	...	...	...	160	165	170	175	180	185	190	195	200	205	210	215	220	225	230	
145	...	...	...	165	170	175	180	185	190	195	200	205	210	215	220	225	230	235	1:75
150	...	...	...	170	175	180	185	190	195	200	205	210	215	220	225	230	235	240	
155	...	...	...	175	180	185	190	195	200	205	210	215	220	225	230	235	240	245	
160	...	...	...	180	185	190	195	200	205	210	215	220	225	230	235	240	245	250	1:70
165	...	...	...	185	190	195	200	205	210	215	220	225	230	235	240	245	250	255	
170	...	...	...	190	195	200	205	210	215	220	225	230	235	240	245	250	255	260	
175	...	...	...	195	200	205	210	215	220	225	230	235	240	245	250	255	260	265	
180	...	...	...	200	205	210	215	220	225	230	235	240	245	250	255	260	265	270	1:65
185	...	...	...	...	210	215	220	225	230	235	240	245	250	255	260	265	270	275	
190	...	...	...	...	215	220	225	230	235	240	245	250	255	260	265	270	275	280	
195	...	...	...	...	220	225	230	235	240	245	250	255	260	265	270	275	280	285	
200	...	...	...	...	225	230	235	240	245	250	255	260	265	270	275	280	285	290	
205	...	...	...	...	230	235	240	245	250	255	260	265	270	275	280	285	290	295	1:60
210	...	...	...	...	235	240	245	250	255	260	265	270	275	280	285	290	295	300	
215	...	...	...	...	240	245	250	255	260	265	270	275	280	285	290	295	300	305	
220	...	...	...	...	245	250	255	260	265	270	275	280	285	290	295	300	305	310	
225	...	...	...	...	250	255	260	265	270	275	280	285	290	295	300	305	310	315	
230	...	...	...	...	...	260	265	270	275	280	285	290	295	300	305	310	315	320	
235	...	...	...	...	...	265	270	275	280	285	290	295	300	305	310	315	320	325	1:55
240	...	...	...	...	...	270	275	280	285	290	295	300	305	310	315	320	325	330	
245	...	...	...	...	...	275	280	285	290	295	300	305	310	315	320	325	330	335	
250	...	...	...	...	...	280	285	290	295	300	305	310	315	320	325	330	335	340	
255	...	...	...	...	...	285	290	295	300	305	310	315	320	325	330	335	340	345	
260	...	...	...	...	...	290	295	300	305	310	315	320	325	330	335	340	345	350	
265	...	...	...	...	...	295	300	305	310	315	320	325	330	335	340	345	350	355	
270	...	...	...	...	...	300	305	310	315	320	325	330	335	340	345	350	355	360	1:50
275	...	...	...	...	...	...	310	315	320	325	330	335	340	345	350	355	360	365	
280	...	...	...	...	...	...	315	320	325	330	335	340	345	350	355	360	365	370	
285	...	...	...	...	...	...	320	325	330	335	340	345	350	355	360	365	370	375	
290	...	...	...	...	...	...	325	330	335	340	345	350	355	360	365	370	375	380	
295	...	...	...	...	...	...	330	335	340	345	350	355	360	365	370	375	380	385	
300	...	...	...	...	...	...	335	340	345	350	355	360	365	370	375	380	385	390	
305	...	...	...	...	...	...	340	345	350	355	360	365	370	375	380	385	390	395	
							1:20		1:25		1:30		1:35		1:40			1:45	

* For mild water circulation (average temperature 180°), add one third = 33 per cent.

* For stores (15,000 to 20,000 cubic feet), deduct one third = 33 per cent.

GENERAL PROPORTIONS OF LOW-PRESSURE STEAM AND WATER APPARATUS.

The following table has been prepared to show *approximately* the relative sizes of different parts of heating apparatus as required and used in practice with low-pressure steam, and the *closed tank system of heating by water circulations.*

It is also intended to give at one glance, and under a proper heading, the relation of each part of a heating apparatus to the other. While not assuming that these ratios are those which should be applied in every particular case, they represent the general and average conditions, and the data that is applied, with certain modifications, which each particular case requires.

It should be explained that the letters where introduced into formulæ in the headings refer to the columns in the table bearing that number at the top; for instance, the horse-power corresponding to heating surface in the boiler of 250 square feet is B (250) divided by 15 = 16.7, as shown in column A opposite 250 in B.

This table (No. 22) will be found very convenient for architects, builders, and others, who desire to arrive at some one detail of a heating apparatus without wading through a number of calculations, or, when having some one or two items, they wish to arrive at the corresponding relation of some other part. For instance, having the cubic contents of a building, say 25,000 or 100,000 cubic feet (column O), then any corresponding detail of material may be found by reading the same line to the left.

Columns A and B show the horse-power of boiler, and the number of square feet of heating surface to supply the radiators, 1 foot of boiler surface being taken as equal to 6 feet of radiator. (*In water heating, 1 to 10 is ample.*) This allows for increased duty sometimes demanded. Fifteen square feet of the boiler surface are considered as representing 150 to 200 square feet of water radiator.

The dimensions of the furnace and grate as given in columns E, F, and G show the area of flue sufficient to properly discharge the products of combustion. This is the key to the efficiency of the whole plant. (See remarks on chimneys, pages 484, 485.)

In this connection we may remark that, while this table is put forward as only the approximate data, size, and relation for any particular use, that the results found (table) have been checked up from many examples in the author's own construction.

Column H shows the distances that the radiating surfaces can be carried from the boiler with the sizes of supply (column I).

Columns K and L indicate the limits within which the number of one-inch branch pipes should fall. In column K the velocity is the same for the fluid in both main and branches, while with as many branches as are shown in column I, the friction is the same for equal lengths of both main and branches; thus the same volume of the heating fluid encounters equal resistance in passing.

Column N may be taken as proportional to the cost of the whole apparatus, the basis of estimate being $1.25 of cost for every square foot of radiation. Thus a water apparatus with 6,000 square feet of surface would, in general, cost in the vicinity of 6,000 x 1.25 = $7,500 to erect.

PRACTICAL EXAMPLES OF BOILER PIPES AND RADIATORS.

Thus from the table we may read, right to left under column O: "Residences or dwelling of 50,000 cubic feet of space (direct and indirect radiation) — 1,000 feet pipe to carry it 3 inches; boiler surface 167 square feet, and grate surface 8 feet." This is the data of water apparatus at No. 25 *Niagara Square.* See pages 454 and 455.

Similarly from column P we read: 499,000 cubic feet; radiation 7,000; size pipe to carry the surface 8 inches; boiler 77 horse-power.

This is substantially data from the Pierce Building. See table, page 441.

So at table we read under column Q: contents 765,000 cubic feet, radiators 8,500, main pipe 9 inches, boiler power 94 horse-power.

This is, as seen, the data from the county buildings at Springfield: 8,720 feet of radiators, the space being 749,000 cubic feet. See table, page 447.

TABLE No. 22.

General Proportions of Low Pressure Steam and Water Apparatus (at Similar Temperatures) for AVERAGE CONDITIONS.

BOILER.				FURNACE.			WROUGHT IRON PIPE LINES.					RADIATORS.		SPACE WARMED.—CUBIC FEET.		
Horse Power $= \frac{B}{15}$	Square Feet of Heating Surface = N ÷ 6.	Pounds of Water Evaporated per Hour = N ÷ 3.	Cubic Feet Steam per Minute = C × ⅓.	Pounds of Coal per Hour.	Square Feet Grate Surface.	Size of Flue. No. of Square Inches.	Length of Supply Pipe $= \frac{N}{10}$	Inside Diameter of Supply Pipe $\sqrt{N} \div 10$.	Surface of Supply Pipe, Square Feet.	Number of 1" Branch Pipes Same Area as Main $= I^2$	Number of 1" Branch Pipes Same Friction as Main $= K \times \sqrt{I}$	Pounds of Water Condensed by Radiators per Hour $= N \times \frac{3}{10}$.	Square feet of Radiation. Approximate Cost (Whole Apparatus), $1.25 per Square Foot.	RATIO OF HEATING SURFACE TO CUBIC FEET SPACE WARMED.		
														1:50	1:70	1:90
														Residences. Indirect Heat, Steam, or Water Circulation.	Commercial Buildings, Small Stores, Offices.	Public Buildings, Prisons, Asylums, when the Heat is *Continuously Maintained.*
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
5.5	83	167	56	F × 6 25	B ÷ 20 4.1	E × 2.9 73	50'	2"	31	4	6	150	500	25,000	35,000	45,000
11.1	167	333	111	50	8.3	145	100	3	92	9	16	300	1000	50,000	70,000	90,000
16.7	250	500	167	75	12.5	218	150	4	177	16	32	450	1500	75,000	105,000	135,000
22.2	333	667	223	100	16.7	290	200	4½	261	20	43	600	2000	100,000	140,000	180,000
27.8	417	833	278	F × 8 123	B ÷ 27 15.4	E × 2.1 258	250	5	397	25	56	750	2500	125,000	175,000	225,000
33.3	500	1000	333	148	18.5	311	300	5	477	25	56	900	3000	150,000	210,000	270,000
38.9	583	1167	389	173	21.6	363	350	6	607	36	88	1050	3500	175,000	245,000	315,000
44.4	667	1333	444	198	24.7	416	400	6	693	36	88	1200	4000	200,000	280,000	360,000
50.	750	1500	500	222	27.8	466	450	7	891	49	130	1350	4500	225,000	315,000	405,000
55.5	833	1667	556	F × 10 252	B ÷ 33 25.2	E × 1.9 479	500	7	990	49	130	1500	5000	250,000	350,000	450,000
61.1	917	1833	611	277	27.7	526	550	7	1089	49	130	1650	5500	275,000	385,000	495,000
66.7	1000	2000	667	303	30.3	576	600	8	1351	64	181	1800	6000	300,000	420,000	540,000
72.2	1083	2167	723	328	32.8	623	650	8	1464	64	181	1950	6500	325,000	455,000	585,000
77.8	1167	2333	778	353	35.3	671	700	8	1579	64	181	2100	7000	350,000	490,000	630,000
83.3	1250	2500	833	379	37.9	720	750	9	1904	81	243	2250	7500	375,000	525,000	675,000
88.9	1333	2667	889	404	40.4	768	800	9	2030	81	243	2400	8000	400,000	560,000	720,000
94.4	1417	2833	944	429	42.9	815	850	9	2157	81	243	2550	8500	425,000	595,000	765,000
100.	1500	3000	1000	454	45.4	863	900	9	2284	81	243	2700	9000	450,000	630,000	810,000
105.5	1583	3167	1056	480	48.	912	950	10	2676	100	316	2850	9500	475,000	665,000	855,000
111.1	1667	3333	1111	505	50.5	960	1000	10	2817	100	316	3000	10000	500,000	700,000	900,000

CHIMNEYS.

It is safe to say that no one detail or feature of a heating apparatus is so important as a properly constructed chimney flue; as, while every other detail may be perfect, no efficient or valuable work can be obtained if the draught is weak and sluggish or limited to only the most favorable conditions of wind and weather.

Whatever the height and area of the chimney, it should be carried up above the highest point of the roof, be covered with a cap to prevent down draught, and the *slope of the wall around the top should be at an angle of forty-five degrees.*

An attention to these details when constructing a building will save much trouble and annoyance afterwards to all parties; but the writer is compelled to state that a good chimney or ventilating flue, in either new or old buildings, is the exception rather than the rule, while without a good flue and draught, no boiler will show up to any advantage, and an engine or heating plant attached to it will suffer and be defective and crippled in proportion as this important adjunct of power has been neglected.

When a good flue is provided in the proper location, both time and money are saved, as a restricted flue requires more heat to create draught than one that is ample. The power of any flue being in proportion to the difference of temperature between it and the outside air, table No. 26 has been arranged to show this power for almost every possible condition, while table No. 22 gives the area of chimney flue for boilers of different sizes. This table also includes the *general proportions* of low-pressure steam and water heating apparatus for *average conditions.*

Yet how are we to obtain chimney flues of proper area, height, and formation? Who, as a rule, have control of these important articles of work? Generally the architect is supposed to dictate this, as all other details of construction; but not being an engineer, or familiar with the work of boilers and grate surfaces, how can he specify what he does not understand? More often this important detail is left to others, to his draughtsman, while the carrying out and up of any flue falls lightly upon the mason, and finally upon the bricklayer, who, having not a particle of knowledge of the requirements, and less interest, the chimney flue is invariably the weakest member of the whole construction, and fails when only a reasonable demand is made upon it.

Lately, however, after thousands of failures in this important matter, the heating firms and even the owners of buildings are getting alive to the demands and to the responsibilities of this chimney question, while the more practical and even legal side is seen to advantage in the late appeal and decision of the Court of Common Pleas of New York.

THE RESPONSIBILITY OF AN ARCHITECT.

[*] "The case of Hubert *vs.* Aitkin, recently decided in the Court of Common Pleas of New York City, gave Judge Van Hoesen occasion to define the relation of an architect to his client in its incidental responsibilities. The question in the particular case was as to whether this architect was liable to damages for the insufficient size of a chimney for steam in an apartment house, he having relied on the judgment in that respect of the steam-heating contractor, which proved at fault.

"The action was brought by the plaintiff, Phillip G. Hubert, an architect, against John W. Aitkin for the value of his services; and the defence was that the area of the chimney flue provided in the chimney was inadequate for the service of the boiler, so that the proper consumption of the coal could not be secured; and that on account of this deficiency in the chimney flue the defendant will be obliged to build a new chimney flue on the outside of the building, and that the necessary cost and expense thereof will be $1,000. In commenting on the case, the judge said: —

"The plaintiffs are architects of standing, who assume to be able to plan and superintend the construction of first-class apartment houses, to be heated by steam and to be provided with every convenience demanded by the tastes of the day.

"They are not architects in a rural community, but in the first city in America. Steam heating is, as we all know, common, if not a necessity, in all apartment houses of large size and of a high class. It is true that houses of this description are of recent introduction; but they are now a very important part of our system of economics, for in some of the new streets they are more numerous than private residences or tenements of the kind that were formerly in vogue. The architect who undertakes to construct a house that is heated by steam is groping in the dark unless he knows how large a chimney is required. It is as necessary that the architect should know what is needed to make the steam-heating apparatus serviceable, as it is that he should know how sewer-gas should be kept out of the house. No one would contend that at this day an architect should shelter himself behind the plumber, and excuse his ignorance or the ordinary appliances for sanitary ventilation, by saying that he was not an expert in the trade of plumbing. He is an expert in carpentry, in cements, in mortar, in the strength of materials, in the art of constructing walls, the floors, the staircases, the roofs, and is in duty bound to possess reasonable skill and knowledge as to all these things; and when, in the progress of civilization, new conveniences are introduced into our homes, and become not curious novelties, but the customary means of securing the comfort of the unpretentious citizen, why should not the architect be expected to possess the technical learning respecting them that is expected of him with other and older branches of his professional studies? It is not asking too much of the man who assumes that he is competent to build a house at a cost of more than $100,000, and to arrange that it shall be heated by steam, to insist that he shall know how to proportion his chimney to the boiler. It is not enough for him to say 'I asked the steam fitter,' and then throw the consequences of any error that may be made on the employer that engages him, relying upon his skill. Responsibility cannot be shifted in that way. In the case of Moneypenny *vs.* Harland, it was held that if a surveyor be employed to erect a bridge and form the approaches to it, he is bound to ascertain for himself by experiments the nature of the soil, even although a person previously employed for that purpose by his employer has made such experiments, and has given him the result at his employer's request; and if the surveyor makes a low estimate, and thereby induces persons to subscribe for the execution of the work who would otherwise have declined it, and it turns out that, owing to his negligence and want of skill, such estimate is grossly incorrect, and that the work can be done only at a much greater expense, *he is not entitled to recover for his services.*

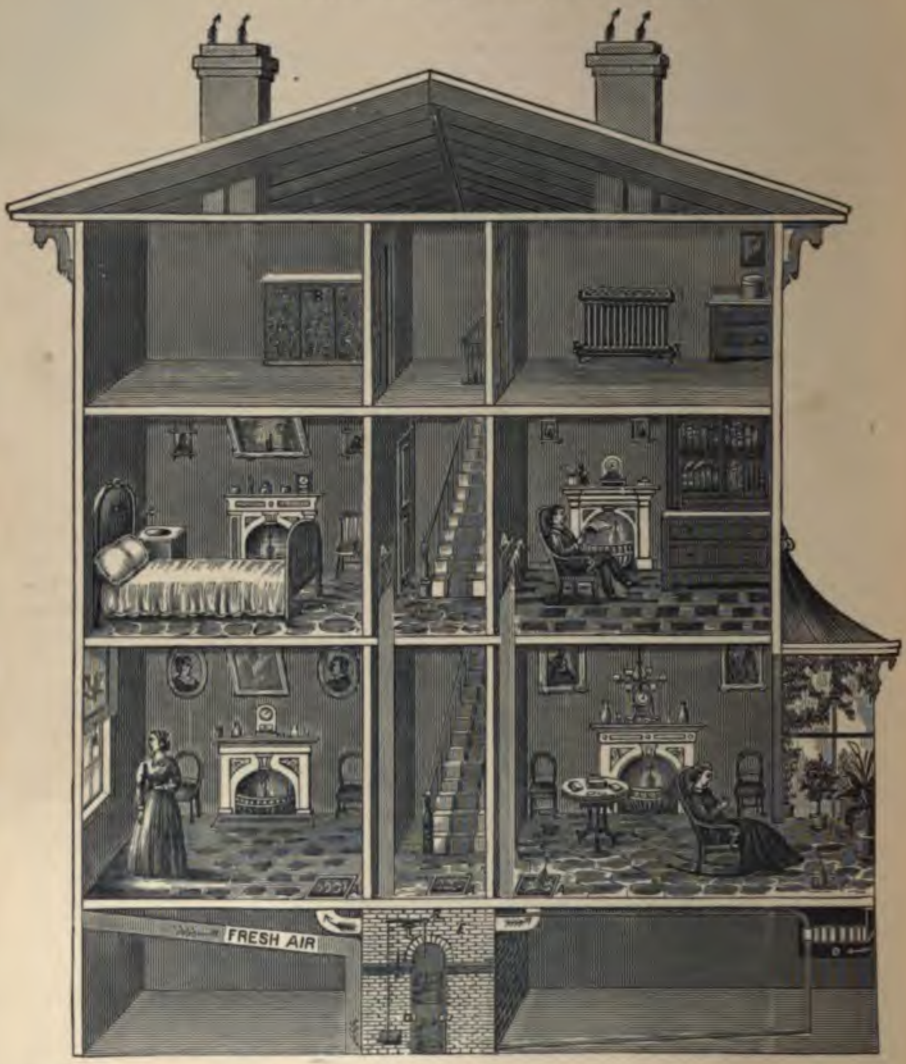
"*The court at general term decided that this sum of* $1,000 *necessary for the construction of a new chimney flue, must be deducted from the claim of the plaintiff and architect for his services.*"

[*] *The Sanitary Engineer*, Jan. 26, 1889.

PLATE NO. 46.

GENERAL ARRANGEMENTS OF STEAM AND WATER HEATING

By "Direct" and "Indirect" Radiation.



On the left of the hall is the parlor, heated by register from the main warm-air chamber in basement.

On the right is the living-room, with large bay window, warmed like the parlor by register, and getting the benefit of *water heat when there is no steam*, and also by the outside stack of radiators, placed under the bay window, and connected by supply and return pipes to the boiler.

The second and third stories are heated in the same manner as the parlor, or by direct radiation, with pipes leading from the boiler in the cellar to direct radiators in the several rooms. The ventilation is by the chimneys as shown.

CHAPTER XXVI

THE VENTILATION OF BUILDINGS.

PART VI.

THE air we breathe, the house we live in; the health, comfort, and prosperity of humanity,—here indeed are themes for the pen of the scholar, the physician, and the scientist.

That these are generally the writers that contribute learned and graceful essays on the various branches of this manifold subject, renders any less able and restricted treatment liable to seem tame and uninteresting, at least to the general reader.

It is a source of regret that this important and all-controlling agency in any heating operations should be left to the last, limited to a detached or sectional treatment; yet this has seemed necessary, since heat, its generation and transmission, properly come before methods and results of application, and because we have already largely exceeded our estimate of time and space in which to conform to our title page.

While we do not propose to enter extensively on the various and far-reaching themes connected with ventilation, there are certain leading ideas and principles it is not best to omit. As there is much diversity of opinion as to the demand, also the methods of meeting it, it seems well to consult authorities, and, as we have before remarked, avail ourselves of the ideas of those who have not only studied the subject intelligently, but have put their thoughts in clear and practical language.

The older treatises on ventilation were, as might be inferred, by English and European writers, and related mainly to the need of a pure-air supply, and such methods to secure it as were applicable to their climate and lesser demands. Their knowledge of the constitution of the atmosphere was correct, also the sources and amount of contamination suffered by the air in all enclosed spaces. That some of their ideas and many of their devices for removing air were crude and inefficient, is true; but, had the designer and builder of those days assisted to render operative a quarter part of the intelligent methods offered by these writers, they would not so long have remained without any recognized system of air supply and removal.

This last remark will apply with equal and greater force to our own time, since we are not to-day using one half the means at our disposal for securing a pure-air supply for our dwellings and public buildings.

Among the early and practical writers on ventilation we may mention Charles Hood, F. R. S., London, 1837 to 1879. This book on warming and ventilation, although now in its sixth edition, is considered one of the best treatises in this important line of heat and its application to buildings. Stoves, furnaces, steam, and hot water are considered as agents. He also went extensively into the matter of gravity and mechanical ventilation, and gave practical estimates of the efficiency and cost of each method.

Another of the older works on ventilation and its kindred subjects is that of David Boswell Reid, M. D., F. R. S. C., 1844; also that of Charles Tomlinson, "Warming and Ventilation," 1864, republished by Crosby, Lockwood & Co., 1878.

A "Treatise on Heat," by Thos. Box, 1868–1876, last edition 1880, is one of the best general reference books in this important line of engineering. Box gives much attention to ventilation by heat inside of shafts or chimneys, and also to the mechanical methods. It was from a study of this practical author that the writer secured the lines for his ventilating wheel, drawings, and data, which are given in the following pages.

We may mention F. Schuman, C. E., 1877, Geo. Rafter, 1878; also Butler's treatise, re-edited by James L. Greenleaf, C. E., 1878.

One of the latest and perhaps only connected American work on *ventilating and warming* is that by Dr. John S. Billings, M. D., LL. D., and Surgeon of the United States Navy. This book was published by the then *Sanitary Engineer* Co., of New York, 1884. It gives a liberal treatment of the subject, and furnishes examples and illustrations of modern buildings that have been warmed and ventilated by mechanical methods. It also contains a paper and a table by the late Robert Briggs on the proper construction of ventilating fans. While these are all found in our list of books consulted, we mention them now, as those on whom, with many others, we shall draw for valuable facts and illustrations; not, as before stated, within the writer's *personal* knowledge, but all the more valuable that they are from the pen and practice of those who, with better education and facilities, have given both time and talent to this important branch of heat engineering.

We have noticed in a former place (Chapter XXI.) the works and writings of Henry Ruttan. In the following pages we shall briefly quote from these practical writers and engineers as the best introduction to the sciences involved and their bearing on ventilation.

*"Ancient Egypt, the site of the earliest civilization whose remains have been spared by time, appears to have been somewhat acquainted with the needs of ventilation. In the pyramid of Cheops, probably older than Abraham, a passage exists, seemingly to have had the purpose of conveying air into and out of a chamber in the interior of the structure. Acron, a Greek philosopher and physician, in the century before Hippocrates, is said to have arrested an epidemic in Athens by lighting fires in several places in the city, to change the air. Celsus, the great Roman physician, alludes in his writings to the beneficial action of fire, the sun's heat, and elevated exposure, in purifying the air of a sick room. The ancient Romans sometimes employed great bellows for ventilation. In Germany, in the sixteenth century, bellows and also rotary fans were used to inject fresh air into and force foul air out of mines. Desaguliers imitated this in England in the eighteenth century, and also contrived a revolving fan to ventilate the House of Commons, by drawing the foul air out at the top of the building. This arrangement was in use for nearly eighty-four years. Dr. Hale, of London, during the same century, invented what was called the "ship's lungs," for airing, by a kind of bellows, the holds and other parts of vessels at sea. Sutton, a London brewer, near the same time attained a similar result by utilizing the cooking fire on a ship's deck. Hospital ventilation, through aspiration by heated flues, was introduced into England by Sir George Paul in 1820. Dr. Arnott, a little later, did a great deal to stimulate attention in England to ventilation. His chimney-place valve is still a great deal used.

"No educated person denies the importance of ventilation, but scarcely one in a hundred of the best-educated persons gives enough practical attention to it. It is proper, in this place, to go down somewhat to the elements of the subject. Why do we need to ventilate at all? Because *we have to breathe; and in breathing we use up and spoil the air.* Everybody knows what happens in drowning; air is for a minute or two kept out from the lungs by water, and the submerged person dies. So when a man goes into a beer vat lately emptied of its liquid, but leaving some of the gas of fermentation,—carbonic acid,—behind, he falls over, and, unless at once rescued, loses his life. Sleeping in a room in which charcoal is burning away from an open chimney has likewise often been fatal, and was employed by suicides for shuffling off this mortal coil. In these cases it may be said the air is poisoned. This is true; but it is not more certainly nor even so badly poisoned as it is by human breaths and the exhalations from our bodies. Charcoal gas is carbonic acid. We exhale that, and besides, with every breath, and from all the pores of the surface of the body, deleterious organic matter."

* Hartshorne.

"This combination when concentrated will kill more quickly than gas produced by simple combustion alone. In the famous instance of the 'Black Hole of Calcutta,' always cited in connection with this subject, one of the survivors of the night's long imprisonment (of one hundred and forty-six men in a room eighteen feet square) mentions that, although the room had in it two small windows, all but twenty-three men died; several of them with different symptoms from those produced by breathing carbonic acid gas alone. Another example of the same thing is the following: A steamer (the "Londonderry") was overtaken in the Irish Sea by a storm. The passengers, about two hundred, having been ordered below, the captain, to prevent water getting in, battened down the hatches. Before their suffering and alarm compelled him to set them at liberty, seventy-two had died of suffocation. There is, then, immediate danger from want of ventilation. But this is far from all. An impure air may poison us slowly. Typhus fever (jail fever, camp fever, ship fever, — of different places) may, I am well convinced, be engendered by this cause alone, as well as by contagion. Typhoid fever and diphtheria are at least much promoted by it. And without any such diseases, a low state of the health, with increased liability to scarlet fever, measles, etc., and a greater probability of death when they occur, is a constant effect of close living.

"Pulmonary consumption and other affections of the chest, as pneumonia and bronchitis, are much more common and more fatal with those who live all the time in ill-ventilated rooms, than in those who are exposed to the inclemencies and vicissitudes of the weather. This is a fact which, if it were generally appreciated, might make a great difference in the manner of living of many people.

"Air consists of two gases mixed together. Referring to larger works for more precise details, we may say that these are about four-fifths nitrogen and one-fifth oxygen. The latter is the vitalizing, indispensable principle; the nitrogen merely dilutes it. Also the air contains a varying amount of watery vapor, which we cannot do without, but which may be more or less disadvantageous by excess; a quantity of carbonic acid averaging, in the open air, three or four parts only in 10,000; and other ingredients, gaseous, vaporous, and even solid (dust) present or absent, according to locality and circumstances. Of these non-essentials of the atmosphere, the organic matter derived from human beings, other animals, and plants, whether living or dead, is the most important, because capable of doing the most harm by its decomposition and poisonous action."

For a detailed estimate of the effect and amount of the different sources of contamination of the air, see page 494; also for amount of air requisite, table No. 25, page 522.

NEEDED INFORMATION.

Advice regarding fresh air has not been lacking in amount.*

"Even the most ignorant have some indistinct notion that there is such a thing as bad air, and that it is not good to breathe it.

"Teachers of hygiene proclaim to pupils the virtues of pure air, shut up in schoolrooms where it is impossible to get it.

"Physicians advise their patients to take fresh air, and this by going out of doors, thus tacitly realizing that it cannot be found indoors. Preachers in churches, where deadly gases from the lungs and poisonous organic emanations from the skin are imprisoned from week to week, emphasize the importance of properly preserving the physical body. There is a universal recognition that it is bad to breathe impure air; there is ignorance no less universal of the conditions of how to avoid it. When the nature and composition of a deadly drug are known and marked 'Poison,' it is properly avoided. In the following pages we shall see how much of the air we breathe should be labeled with skull and cross-bones.

"Where is the impure air? What makes it impure? What are the nature and amount of its impurities? These are important questions, which among the educated are tolerably well known. But when these impurities exist in an occupied room, how are they to be eliminated and replaced by pure air of the proper temperature?

"These are questions which are no less important, but they are questions that are seldom answered. How to know where impurities exist; how to expel them as fast as formed, and supply their places with the pure, life-giving element, is a problem second in usefulness to none other. Of the difficulty of the problem we have ample evidence in the fact that it has been but partially solved, and in general practice almost wholly ignored."

In the light of science, a human being is really a furnace or a small steam boiler, requiring a stated amount of solid, liquid, and gaseous food to produce certain results in work or force. The one exactly represents the other; we may fairly estimate the amount of carbon and hydrogen required to be in proportion to the amount of physical and mental exercise.

To quote the words of Professor Tyndall: "In the animal body the carbon and hydrogen of the vegetable are again brought into contact with the oxygen from which they have been divorced, and which is now supplied by the lungs. Reunion takes place, and animal heat is the result. Save as regards intensi [illegible] is no difference between the combustion that goes on wit [illegible] t of an ordinary fire."

We see, then, of what vital consequence is the presence of oxygen in the atmosphere; without it, fires and lights will not burn, our food will not digest, and the blood remains unpurified. This is shown by the pale faces and purple lips of people living in close and overheated rooms. These are the forerunners of certain death to persons deprived of the life-sustaining oxygen.

"None except he who has given special study to the facts begin to realize the injurious effects of breathing impure air. Every one knows what a disagreeable feeling accompanies the breathing of impure air; that a feeling of stupor, inactivity, drowsiness, and sometimes nausea, headache, and vertigo, result directly from the occupancy of ill-ventilated rooms. These sensations are temporary, and are experienced only while the cause is active, and usually the only thought is to temporarily relieve the inconvenience by a recess or a break for fresh air.

"Seldom do persons reflect on the ulterior effects of these violations of nature's laws; and when the outer air is reached, and long draughts of the pure element relieve the oppressed sensations, and send the invigorating, oxygenated life-blood current coursing through the system, raising the spirits and clearing the brain, their reflection usually ends with relief, and, when more or less resuscitated and rescued from the fatal stupor (I use the phrase advisedly), the unsuspecting victims crawl back into their 'Black Holes,' again to fill the system with the gaseous poison, thinking it only an unpleasant duty, the immediate endurance of which will bring subsequent freedom and relief. But this is a great mistake; the temporary suffering incident on the act of breathing vitiated air is but a small part of the objection to be urged against it. The principal charge against the breathing of impure air is that it sows the seeds of disease and death, the length of time in which the subject will succumb being in proportion to his power of endurance.

"No subject has been more carefully and intelligently studied than the direct and ultimate effects of impure air on the human system, and on no subject is there more unanimity of competent opinion. Besides the general debilitating and weakening effects, which render the system susceptible to infectious diseases, breathing impure air is believed by the best authorities to be a direct cause of phthisis, consumption, and its accompanying diseases,—catarrh, bronchitis, pneumonia, and many others.

"The individual effects of breathing separately the foreign gases usually found in the atmosphere need not be considered here; but it is their combined effect, combining as they do with organic emana[illegible] from the skin and lungs, that chiefly concerns us in con[illegible] effect of impure air made so by respiration."

"On the disease-producing effect of air rendered impure by respiration we have a host of authorities. The following statistics are from the 'English Sanitary Record,' given by Ransom, showing the comparative death-rate from pulmonary diseases in different localities where the relative impurities are known to vary in about the same ratio as shown by the death-rate. For all England, 1865-76, 3.54; for Salford, 5.12; Manchester, 7.7; Westmoreland, one of the healthiest of counties, 2.27; North Wales, 2.51. It is of course not to be forgotten that other causes, such as intemperance, insufficient and improper food, sedentary pursuits, etc., also conspire in these unfavorable localities to produce the final result. 'But,' as Dr. Parkes remarks, 'allowing the fullest effect to all other agencies, there is no doubt that breathing the vitiated atmosphere of respiration has a most injurious effect on health.' Consumption is commonly attributed to sudden and undue exposure to wet and cold, want of sufficient food, clothing, etc.; but Baudelocque says 'that impure air is the great cause of consumption, and that hereditary disposition, uncleanness, want of clothing, bad food, cold and humid air, are by themselves non-effective.' The following paragraph from 'Parkes' Hygiene' I copy for the weight of authority in the eminent names mentioned therein:—

'"Carmichael, in his work on scrofula (1810), gives some most striking instances where impure air, bad diet, and deficient exercise concurred together to produce a most formidable mortality from phthisis. In one instance, in the Dublin House of Industry, where scrofula was formerly thought to be contagious, there were in one ward, sixty feet long by eighteen feet wide, thirty-eight beds, each containing four children; the atmosphere of the ward was so bad that the air in the morning was unendurable. In some of the schools examined by Carmichael the diet was excellent, and the only causes for the excessive phthisis were the foul air and the want of exercise. This was also the case in the house and school examined by Neil Arnott in 1832.

'"Lepelletier also records some good evidence. Professor Alison, of Edinburgh, and Sir James Clark, in his invaluable work, lay great stress on it. Neil Arnott, Toynbee, Guy, and others brought forward some striking examples before the Health of Towns Commission.'

"Carbonic dioxide, CO_2, is commonly considered the poisonous substance in the atmosphere; this is in the main untrue, for moderately large quantities, when pure and mixed with air, can be breathed with impunity. CO_2, by its inability to support life, will produce asphyxia by shutting out the needed oxygen, but it cannot be regarded as a poison. Substantially the same conclusions have been reached by DeMarquay, Angus Smith, W. Muller, Eulenberg, and Hirt, all of whom have made close investi

THE AIR.—SOURCES OF CONTAMINATION.

A. *Production of Carbonic Acid by Respiration.* "When air passes into the lungs it undergoes a chemical change whereby a certain amount of carbonic acid is produced. This when expired adds to the impurity of the air, and, were its production by respiration continued for a sufficient time in any tight space, the air would ultimately become so impure as to cause death.

"It has been found by experiment that air in its normal condition contains in all parts of the world an amount of carbonic acid equal to from 3 to 4 volumes in 10,000. That some must exist in the air, will be readily inferred by considering that respiration and combustion always produce this gas. The amount, however, was only determined by the researches of Regnault, who analyzed air from many localities. When carbonic acid is the only impurity, from 8 to 10 volumes in 10,000 may be respired without serious inconvenience, though 6 volumes in 10,000 is taken as the limit of good ventilation for reasons to appear hereafter. An adult produces 0.6 of a cubic foot of carbonic acid per hour.

B. "*Increase of Moisture from Bodily Exhalations and Respiration.* The amount of moisture present in the air at different times varies greatly. Observation shows that there are certain amounts of moisture which when exceeded lead to a rapid deterioration of the air. From 4.5 to 5.0 grains in a cubic foot of air at 60°–62° is the limit of good ventilation.

C. "*Organic Impurities from Bodily Exhalations.* There is always present in illy ventilated apartments, especially school-rooms where children from the poorer classes are present, a certain unpleasant smell which a medical friend of large experience in ventilation characterizes as 'cheesy.' In simple justice it must be said that this smell is by no means confined to school-rooms of the kind indicated. Excellent examples of it are frequently noticed in concert halls, theatres, lyceums, and in private houses, where even an intimation of uncleanliness would be rank injustice. Organic analysis has thus far been unable to more than detect the simple presence of this ill-smelling enemy of the human race. It has been found, however, that a rapid increase of the organic impurity takes place when carbonic acid exceeds 6 volumes to 10,000, or when moisture rises above 5 grains in a cubic foot of air at 60°–62°. The reason for the limit of carbonic acid and moisture as above given is therefore apparent.

D. "*Heat Thrown off from the Occupants and from the Lights at Night.* It has been determined by observation that an adult gives off 470–490 units of heat per hour, and that an ordinary sperm or tallow candle gives out in burning one hour substantially the same amount. The specific heat of air is 0.238 when water is taken as unity. Consequently the heat from a single person or single candle in one hour would raise 1,974 pounds of air 1°; or, since a pound of air at 60°–62° equals 13 cubic feet (exactly 13.09 at 60°), we have heat enough to raise 25,662 cubic feet of air 1°.*

"It will be shown hereafter that 2,000 cubic feet of air per hour is fair allowance for an adult. It follows that every person and every candle gives out heat enough in an hour to raise the supply for each person from 12° to 13°. If a room were constructed of capacity equal to, say, 10 persons, and the air supply exactly regulated to give each 2,000 cubic feet per hour, the bodily heat alone would increase the temperature of the supply from 12° to 13°.

"A large majority of buildings are lighted now by coal gas. We will therefore consider the amount of heat produced by the combustion of a cubic foot, having ascertained which, it will of course be easy to calculate the elements of rooms for any capacity and number of lights.

"The mean of several tests was 705 heat units per cubic foot of gas. We will take for purposes of calculation 750 heat units per cubic foot.

"Gas burners range from 3 to 6 cubic feet consumption per hour; and, where no especial arrangements have been made for removing the heat of burners and products of combustion, a simple calculation will show the great influence on the health of the occupants of an apartment exerted by this apparently insignificant source of contamination.

E. "*The Production of Carbonic Acid from the Lights.* According to many careful experiments the carbonic acid from a sperm or paraffine candle equals 0.31 cubic feet per hour. Calculation based on the average composition of coal gas shows that the combustion of a cubic foot of gas produces 0.43 of a cubic foot of carbonic acid. . . .

"It is evident, then, that a considerable amount of oxygen is required for the various processes of respiration and combustion going on in confined spaces, and that further deterioration of the air is continually taking place by reason of the presence of nitrogen, previously mixed with the oxygen so removed. That is to say, oxygen, the life-supporting agent in these various processes, is continually being removed; while nitrogen, the inert, useless element, is left behind.

"Air in its normal condition contains 23 per cent by weight of oxygen, and 77 per cent of nitrogen. It will soon result, however, in any confined space where respiration and combustion are going on, that the amount of oxygen steadily decreases, while the nitrogen and carbonic acid increase relatively to the amount of oxygen present.

"A further source of contamination is found in imperfect sewer connections, though this part of the subject has been so often discussed that it is unnecessary to consider it at length here."

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* Geo. B. Rafter.

In some wharf-building work in which the author was once engaged, at Aspinwall (Isthmus of Panama), it was necessary to remove the wreck of a large English steamer that lay across the line where the piles should be driven. Many efforts had been made to remove the obstruction, but without avail, as there was no modern diving apparatus on the isthmus, nor divers to operate it.

A copper bell was made at the company's machine shop. It was cone shaped, 4 feet high, 3 feet 6 inches in diameter at the bottom, and 6 inches at the top, in which a ring bolt was inserted; around the bottom were placed solid iron rings as weights, which, with the "diver," would carry down the enclosed air.

The whole enclosed space was about 13 cubic feet. Deducting 3 for the upper half of the diver's body, this left only 10 cubic feet of air space to subsist upon during a trip to the bottom of the sea and return, the water being from 20 to 30 feet deep. Taking the contents at 10 x 1,728 cubic inches ÷ 480 (the air breathed per minute), we have 36 minutes as the time in which the air would all be passed once through the lungs.

As the writer was the diver, he may say that he found the situation decidedly uncomfortable at the end of *eight to ten minutes*. The suffering and distress was very great; there were ringing and noises in the head, while great drops of perspiration started all over the body. Several times he was taken out unconscious, bleeding at the nose and ears.

Then there was the additional pressure to which the enclosed air was submitted at various depths below the surface. At 5 feet below the surface, pressure inside the bell would be 2.1 pounds to the square inch (additional); at 10 feet, 4.3; at 15 feet, 6.4; at 20 feet, 8.6; and at 30 feet, nearly 13 pounds per square inch on every part of the body. Under these conditions there were a less number of respirations, the air occupying only one half of the original bulk.

The final and dangerous condition was reached when, after several explosions under the wreck, the bell could not be lifted, owing to fouling of the tackle with the splinters blown off the planking. In this emergency there was no relief but in getting lower and lower down in the bell, to reach a stratum of air from which the oxygen had not been entirely extracted. It may be explained that the bell was suspended, raised, and lowered near to the point of operation by the side of the vessel. The wharf had been built to within some 20 feet, so that the man holding the life line was stationed on the wharf; and, in case of the failing of the hoisting tackle, the only remedy was to pull upon the life line, drawing the bell away from the wreck's side, and thus clearing the ropes from the obstruction splinters. True, the bell then filled with water, but this was of little account, as the diver could then be rescued.

WHAT VENTILATION IS.—HOW TO SECURE IT.

*"What is it that we desire to effect by ventilation, and how may we define good ventilation or know whether it has been secured in any given building? Ventilation is ordinarily defined to be the removal of foul and the introduction of fresh air, but this gives a very insufficient idea of what is meant by the word.

"*Ventilation is Securing a Change of Air.* It may be required for the purpose of removing moisture, as in the drying rooms of a cotton factory, or in a cellar, or to keep the air of rooms fit for respiration. In the great majority of cases it includes the idea of a thorough mixing of pure air with impure air, in order that the latter may be diluted to a certain standard.

"*Perfect* ventilation may be said to have been secured in an inhabited room only when any and every person in that room takes into his lungs at each respiration air of the same composition as that surrounding the building, *and not part of which has recently been in his own lungs or those of his neighbors*, or which consists of the products of combustion generated in the building, while at the same time he feels no currents or draughts of air, and is perfectly comfortable as regards temperature, being neither too hot nor too cold. Very rarely indeed can such perfect ventilation be secured, if the number of persons in the room exceeds two or three; in fact, I have never seen but three or four attempts in this direction. One of these was the house of the late Mr. Thomas Winans, of Baltimore, where the floors were perforated uniformly all over the room, as was done by Mr. Reed for the British House of Commons, thus making the floor a gigantic register or grating through which the incoming fresh air, having been previously warmed and moistened in mixing chambers below, is to stream steadily upward at a uniform velocity sufficient to remove all the products of respiration or combustion as rapidly as formed. It requires even more than this to secure the perfect comfort as regards temperature above alluded to; but this will be explained when we speak of the heating and ventilation of large assembly halls. The amount of air required to secure this ventilation is very great.

"The connection of the heating of a house with its ventilation is, of course, inseparable. Now, many persons will cheerfully expend from fifteen to twenty thousand dollars in building a house, putting from three to five thousand dollars into ornamental stone work and cornices, who would not dream of spending from a thousand to fifteen hundred dollars for the necessary hot-water or low-pressure steam apparatus to keep this same house thoroughly and comfo[illegible]d well ventilated.

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*Dr. John S. B[illegible]

*"The ventilation of a building is ordinarily accepted to be the removal of the foul air from within, and its replenishment with pure air from without. This is true as far as it goes; but several other points, of hardly less importance, must also be taken into account. We must not only effect a change of air, but in our climate, and particularly in the winter, the requisite temperature must be imparted to it, and it must be moved through the building in such a manner that currents of all sorts shall be avoided as much as possible.

"Our dwelling stands at the bottom of a sea of air twenty miles deep. We erect brick, stone, or wooden walls about us, and therefore we must find means to get so much of this ocean of air through the building as may be sufficient for our purpose. By opening windows, doors, or other apertures on opposite sides of our house, we can probably get a current of air through our building at certain points. Now, even if we could stand this in stormy or wintry weather, and by night and day, still it would not be ventilation, because there would be only a partial removal or change of the air.

"Every particle and atom of air must go out, or, of course, the process is not perfect. Currents of air, however, through a building, even if they would change the air (which they certainly cannot do, be the process ever so ingeniously contrived), cannot be tolerated in this cold climate, especially in winter, which is the very time when we need the most ventilation. The whole body of air in each apartment must move together, and every local current necessary to its motion must be so guarded and concealed that no inconvenience can be felt by its inmates.

"An old writer says: 'When men lived in homes of reeds, they had constitutions of oak; when they live in houses of oak they have constitutions of reeds.'

"Evidently the truth inculcated is that the better the air and the more bountiful its supply, the healthier is the inmate of a house, be it a palace or a cottage. Too often the very wealth of a house builder militates against his splendid mansion becoming that ideal home of comfort that it should be, and the inmate of some wretched, leaky little hovel, perched on a rocky hillside, will have every advantage over such a one as regards vigor of body and elasticity of spirits.

"Science tells us that there is a needed respiration for the walls of our houses, and that, fortunately for us, whether we are aware of it or not, the materials of which our modern houses are made admit of the passage of air in a greater or less degree.

"Brick, stone, wood, and mortar, solid as they look to us, are easily pierced by that volatile fluid which we call air."

* Henry Ruttan.

"It does not matter for what purpose the place is used. It can be ventilated, heated, or cooled, as circumstances may require, and that, too, with as much certainty as it can be supplied with water or gas.

"Every water closet, urinal, sink, bath tub, and wash basin can be made a means of purifying the air in the place of their location instead of fouling and polluting it, as unfortunately most of the necessary appliances do. Persons of wealth are often found fault with, because they do not have their houses and places of business in a first-rate sanitary condition.

"Are they always to blame for that state of things? I think not. Many of them could tell, if they would, how hard they have tried, and how much they have spent of time and money, to have such a state of affairs brought about, but alas! the results have been far from satisfactory. Indeed, in many cases, disaster has resulted from their well-meant efforts. Disease, and in many cases death, has followed the introduction of so-called modern improvements. Case after case might be cited to prove this statement. Some of the grandest homes ever planned have been desolated by the bad work of empirics and the blundering stupidity of self-styled sanitary engineers.

"Sewers have been, and are even now allowed to belch their foul poisons into the homes of all sorts and conditions of men, and this, too, in despite of health officers and sanitary inspectors. It is dampness and a want of sanitary ventilation that make a house dangerous to live in, and a constant menace to health and life itself. Diphtheria and ulcerated sore throat, rheumatism, headache, dyspepsia, nervous affections, and many forms of disease are caused by living in a confined, humid atmosphere. Such a state of affairs ought not to be; they need not be. Every building can be made healthful by proper ventilation.

"No half-way measures nor make-shift devices will do. If we want a healthy atmosphere in our homes and places of business, we must make it by bringing in the purest and freshest air we can get, and by forcing out the foul and vitiated air as fast as it is generated. Keep the air moving into and out of your premises, — a constant interchange of the old for the new, — and you will have mastered the first and last principles of ventilation.

"The requirements in the way of pure air for three to six persons living in a house of from six to eight rooms are certain and well definable. They are not the same as for a large number of people in a more contracted space, and differently situated as to age and occupation. It is clear that the adult requires more air than the half-grown, and they again require more than the child of from six to twelve years of age. See table No. 25, on pages 520, 522.

HUMIDITY OF THE AIR.*

"The quantity of watery vapor found in the air varies with the locality, temperature, and various local conditions, and is important from a sanitary point of view. The right proportion of moisture in the air constitutes one of the conditions of a healthy climate. In the heating and ventilation of buildings, where the proper proportion of watery vapor is found not to be present, it may be supplied by artificial means.

"A knowledge, therefore, of the proper conditions of humidity, as well as a knowledge of the means of supplying them when absent, is thus seen to be important.

"The sanitary condition of the air, as influenced by humidity, has not received the attention that its importance demands; yet enough has been done to enable us to estimate within limits fairly narrow. Dr. de Chaumont, in some experiments in various rooms containing air of standard respiratory purity, found that the average humidity is 73 per cent of saturation. This, it must be remembered, was taken in England, where the climate is much more moist than that of America. Probably a humidity somewhat less would answer for our climate; but in any case a given standard must be regarded as only provisional, changing with the temperature of the room at the time of testing. 63° Fahr. was the temperature used in the experiments of de Chaumont.

"Some observations have been made in this country by D. L. Huntington, at the Barnes Hospital, Washington, and by Dr. Cowles at the Boston City Hospital. The results are as follows: 'First week in December, 1877: Average external temperature, 38½°. Average temperature of the wards, from 71° to 76° Fahr. Average relative humidity, from 44 to 49 per cent of saturation; of outer air, 74.' This, it will be noticed, shows a much lower per cent of moisture in the room than that given by the English standard; yet it was claimed that, notwithstanding this small quantity, 'a peculiar feeling of freshness and purity was perceived by those who entered the room.'

"In rooms where the air is too dry, it may be moistened in winter by placing shallow vessels of water on stoves, on heating coils of steam or hot-water pipes, or in the hot-air ducts. In summer moistening by artificial means will seldom be required; but when, on account of unusual dryness of the season, the conditions so require, it may be done by sprinkling the floor (not a very advisable method) or by ejecting cold water in sprays through a series of small holes.

"There is a popular idea that air loses its moisture by heating. In fact, since moisture exists in the air, so far as known in the form of vapor and not mechanically suspended, the only way the air can lose moisture is by reduction of temperature to the dew point, and consequent deposition in the form of dew.

[*] G. B. Morrison.

The vapor that is present in the air is diffused throughout the whole space occupied, forming a distinct atmosphere from the other constituents, and having its own density and pressure.

The capacity of air to retain vapor without condensation is, according to the experiments of Dalton, proportional to the numbers 5.82, 7.94, and 10.73 for the different temperatures of 60°, 70°, and 80° Fahr.

When air contains 80 per cent of the amount of moisture required to saturate it, it is said to be damp; 65 per cent, moderately dry; 50 per cent, dry; and 35 per cent, very dry.

At different temperatures the percentage will vary; air that is damp at 60°, or has 80 per cent of moisture, will, if heated to 80°, and no additional moisture absorbed, have only 80 x 5.82 divided by 10.73 equals 44 per cent, and will consequently abstract moisture from everything with which it comes in contact.

Evaporation.— According to Dalton, the laws that govern the evaporation of water in atmospheric air are:—

"1st. The quantity evaporated is in direct proportion to the surface exposed, all other circumstances being alike.

"2d. Any increase in the temperature of the liquid is attended with an increase in evaporation, not directly proportionate.

"3d. Evaporation is greater where there is a stream of air, than where the air is stagnant, and is greater the less the humidity previously existing in the air."

Assuming that the mean temperature during the winter months is about 30°, and that the inside temperature is maintained at 70°, there will be required, according to the table of Dalton, 3.82 grains of water additional per cubic foot of air warmed from the outside to the inside temperatures, in order to restore the air to its average humidity.

Where the air in a room is changed once every hour, rooms of average size, 2,000 to 6,000 cubic feet, require from 1 to 3 pints of water, evaporated every hour, in order to maintain the air at its mean humidity (about 75 per cent of saturation).

The amount of water that a square foot of water surface will evaporate increases rapidly with its temperature. According to some experiments made by Thos. Box when the water is at 70°, 1 square foot of the exposed surface will evaporate 301 grains per hour in calm air, when the air has the average winter humidity.

Under similar conditions to those considered, but with the water warmer,— say at 100°, 130°, and 160° Fahr.,— the evaporation will be respectively 1,097, 3,164, and 7,933 grains of water per square foot per hour; requiring about 3.5, 1.2, and .5 square feet of water surface per 1,000 cubic feet of space in the room.

The following diagram and table illustrate other conditions, page 533.

*CARBONIC ACID NOT THE DANGEROUS ELEMENT.

"It is evident, therefore, that carbonic acid gas, in the proportions in which we find it in the worst-ventilated rooms, is not in itself a dangerous impurity; in fact, we have no evidence to show that *in such proportions it is even injurious.*

"What, then, is the importance of this gas in relation to questions of ventilation? And why do sanitarians lay so much stress upon the results of chemical tests of air with reference to this substance, and on what may seem very small variations in the proportions in which it is present?

"It is because carbonic acid gas is usually found in very bad company, and that variations in its amount, to the extent of three or four parts in ten thousand, indicate corresponding variations in the amount of those gases, vapors, and suspended particles which are really offensive and dangerous; and, also, because we have tests by which we can, with comparative ease and certainty, determine the variations in the carbonic acid, while we have no such tests of recognized practical utility for the really dangerous impurities.

"As a matter of convenience, therefore, we measure the carbonic acid, and thus get a measure of the extent to which ventilation is being effected. Of course we must make sure that the circumstances of the case present nothing unusual, since, on the one hand, carbonic acid may be present in great excess,—as in a soda fountain charging-room,—without indicating great impurity; and, on the other, it is possible that the air of a room may be very dangerous, from suspended organic particles, and yet have carbonic acid present in merely normal amount. This will appear more clearly when we come to consider the ventilation of hospitals for infectious diseases. The man who has a patent sanitary stove or an automatic ventilator will rarely find any disagreeable odor in a room fitted with his appliances. The carbonic-acid test of foul air depends on the fact that when, as a product of respiration, the proportion of carbonic acid in a room increases from the normal amount of four parts in 10,000 to between six and seven parts in 10,000, a faint, musty, unpleasant odor is usually perceptible to any one entering from the fresh air. If the proportion reaches eight parts, the room is said to be close.

"Whenever a man takes the ground that carbonic acid is the special impurity that is to be provided for, and asserts that, as it is heavier than ordinary air, therefore it sinks to the floor, he demonstrates that he is a person who may be a very estimable gentleman, but whose opinions about ventilation should be received with very great distrust."

*Dr. John S. Billings.

UNRELIABILITY OF THE SMELL TEST AS A MEANS OF DETERMINING IMPURITIES.*

"'Of the means,' says Dr. Lardner, 'of estimating physical effects, the most obvious, and those in which mankind place the strongest confidence, are the senses. The eye, the ear, and the touch are appealed to by the whole world as the unerring witness of the presence or absence, the qualities and degrees, of light and color, sound and heat; but these witnesses, when submitted to the scrutiny of reason, and cross-examined, so to speak, become involved in inextricable confusion and contradiction, and speedily stand self-convicted of palpable falsehood. Not only are our organs of sensation not the best witnesses to which we can appeal for exact information as to the qualities of the objects which surround us, but they are the most fallible guides that could be selected. Not only do they fail in declaring the qualities or degrees of the physical principles to which they are by nature severally adapted, but they often inform us of the presence of a quality which is absent, and of the absence of a quality which is present.'

"The organs of sense were never designed by nature as instruments of scientific inquiry; and, had they been so constituted, they would probably have been unfit for the ordinary purposes of life. It is well observed by Locke 'that an eye adapted to discover the intimate constitution of the atoms which form the hands of a clock might be, from the very nature of its mechanism, incapable of informing its owner of the hour indicated by the same hand.'

"Of all the organs of sense, that whose nervous mechanism seems to be most easily deadened by excessive action is that of smelling. The most delightful odors can be enjoyed only occasionally and for short intervals. The scent of the rose, or the still more delicate odor of the magnolia, can be but fleeting pleasures, and are destined for only occasional enjoyment. He who lives in a garden cannot smell a rose, and the wood-cutter in the southern forests is insensible to the odor of the magnolia.

"Persons who indulge in the use of artificial scents soon cease to be conscious of their presence, and one can only stimulate their jaded organs by continually changing the objects of their enjoyment.

"But every day's experience must convince the most careless observer how little dependence can be placed on the sense of smell. We move into a new tenement, for instance, and we are at once sensible of a difference of smell; but in a very few days we become accustomed and entirely insensible to it. We walk into a different apartment of the same building, [illegible] [illegible] our own, and we are distinctly sensible of a peculiarity of [illegible] [illegible] passes away if we remain in the room.

Ruttan.

"We notice the loathing with which a person enters one of our prisons; in a few days he ceases to complain. Pass from the pure air into an unventilated bedroom which has been occupied the night previous by a lodger, and you at once become sensible of a most intolerable smell; yet the person who occupied it was unable to detect anything of the sort. It is just so in the case of badly ventilated houses; the inmates so soon become accustomed to the foul air they are continually breathing, that it is an almost hopeless task to convince him that it is anything but the most pure. In short, such is the uncertainty of our organs, that, delicate and refined as they may be, if our health depended solely upon their indications, they would be worse than useless to the human family.

"It is indeed wisely ordered that our organs of sense should be constituted for active and practical use, rather than that they should, by the delicacy or grossness of their sensation, render us miserable; and it is especially so with the eye. It has been already observed that the eye which was capable of discovering the atoms of which the hands of a clock were made, would fail to inform of the hour indicated by the same hand. It may be added that a pair of telescopic eyes, which would discover the molecules and population of a distant planet, would ill requite the spectator for the loss of that rude power of vision necessary to guide his steps through the city he inhabits, and to recognize the friends who surround him.

"But although no dependence can be placed upon our senses as to what may be good or evil, useful or injurious, yet man is endowed with a mind, and a capacity to investigate scientifically all subjects connected with his physical existence; and this he is as much bound to do as he is to investigate those laws which are placed before us as a guide in our moral existence.

"If, therefore, by ordinary observation, we cannot see the contaminations of the air we breathe, or detect its fetid odor, this is no more a reason why we should set at defiance all experience, both personal and scientific, than it would be for a man who would swallow a poisonous drug merely because he could perceive no difference, either in color or substance, between it and a cup of tea.

"With these facts before us, establishing most clearly the fallibility of our senses and their liability to lead us astray, it obviously becomes necessary for us to go to some other source for reliable knowledge in relation to the subject at hand."

NOTE.—Air can be measured or weighed the same as gas or water, by determining its velocity passing any given opening or flue. Machines for this purpose are shown on page 506.

TESTING SYSTEMS OF VENTILATION AND HEATING.

The actual efficiency of any system of ventilation and heating cannot be ascertained by a mere casual inspection, but only by careful, intelligent, and extensive experiment, and the use of special instruments designed for such investigations.

Among the most important are those here represented. (Plate 47.)

Good thermometers of the usual construction are generally sufficiently accurate for observing the ordinary temperature of the air; but, for noting the temperature of steam or water, the form shown in figure No. 1. is very convenient and reliable. The thermometer tube is enclosed in a circular brass case, the lower end of which is provided with a screw of standard size and thread, by means of which it may be securely inserted in any pipe. The tube projects well down below the threaded portion, and is guarded by a small pipe attached to the bottom of the case. The graduations may be made to read to any requirement. Those for a closed-water apparatus are generally graded from 100° to 300°.

The volume of air flowing through a given passage can be ascertained by finding the velocity of flow, by means of an anemometer, and multiplying this by the area of the cross section of the passage. Figure 2 represents the most approved form of the instrument. The number of feet traversed by the air is shown upon a series of dials. Noting by means of a watch the number of feet traversed in any given time by the air, the velocity per unit of time may be obtained.

A much simpler form, although decidedly larger, is shown in figure 3 for indicating very slow currents. It is very light and carefully balanced, and will render apparent currents which are otherwise imperceptible.

The *pressure* of the air or the *vacuum* in any enclosed space is readily indicated by the *air pressure gauge* in the form constructed for the trade by B. F. Sturtevant, and shown in the following plate, figure 4.

The rubber tube is connected with the space, and the pressure or lack of pressure in this space causes the water to fall or rise according to which condition exists. The bulb is filled with water, and, being of considerable size, a change of level in the tube has practically no effect on the level of the bulb, and consequently a constant head is maintained. The tube is graduated to quarter inches, which may be readily reduced to ounces, when it is known that a column of water 26.672 inches in height will give a pressure of one pound to the square inch, or a column of water 1.67 inches high equals 1 ounce.

* STANDARD INSTRUMENTS FOR ASCERTAINING THE PRESSURE, TEMPERATURE, AND VELOCITY OF AIR.

Plate No. 47.

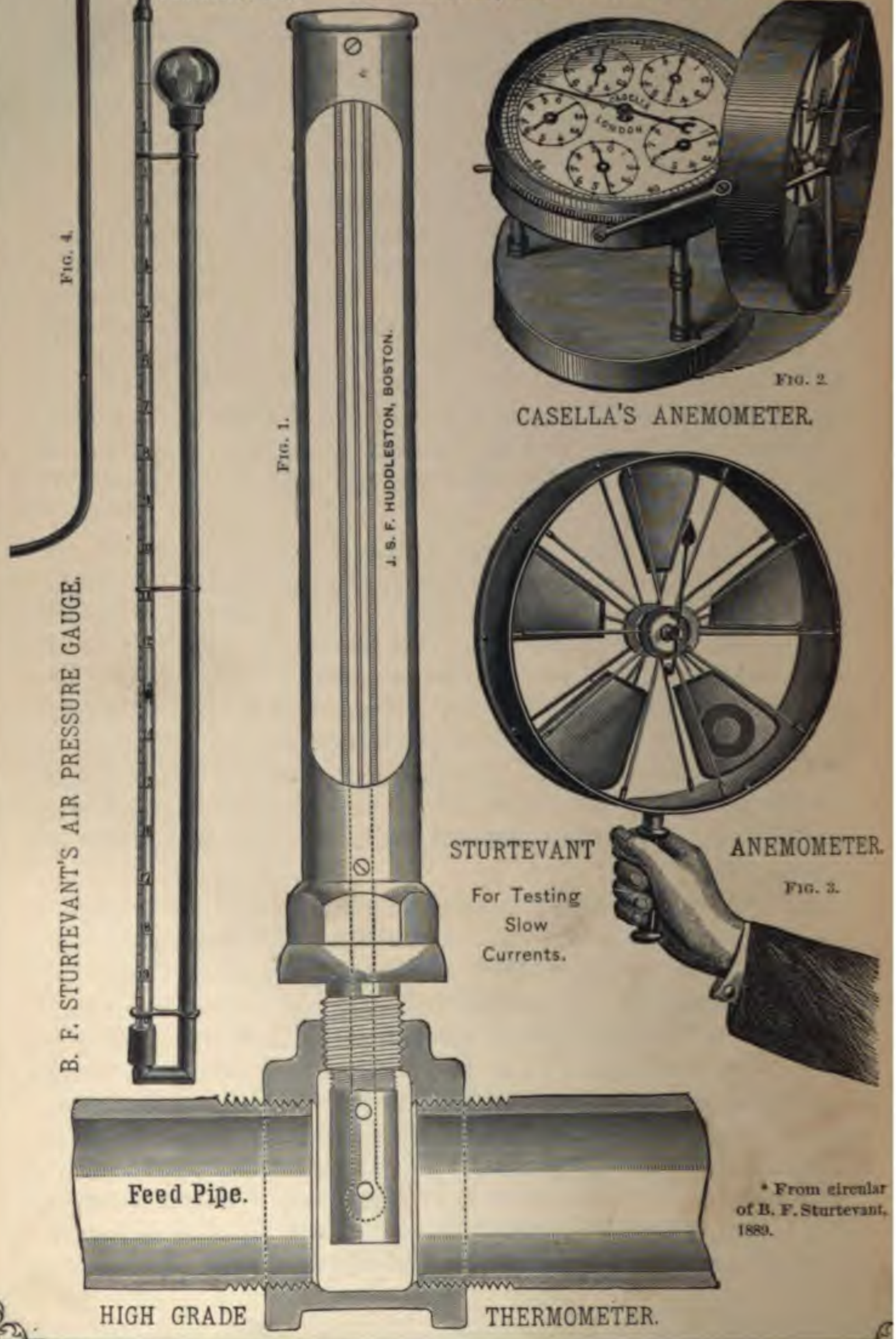
J. S. F. HUDDLESTON, BOSTON.
CASELLA
LONDON
Feed Pipe.

FIG. 4.

B. F. STURTEVANT'S AIR PRESSURE GAUGE.

FIG. 1.

HIGH GRADE THERMOMETER.

FIG. 2.

CASELLA'S ANEMOMETER.

STURTEVANT ANEMOMETER.

FIG. 3.

For Testing Slow Currents.

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* From circular of B. F. Sturtevant, 1889.

CHAPTER XXVII

THE CONDITION OF PUBLIC SCHOOL BUILDINGS.

THE AMOUNT OF AIR REQUIRED.*

IN attempting any answer to this question, made up, as seen, of so many separate and variable issues, it may be stated that the author offers no original data of his own, or solution other than that drawn from the combined statements, testimony, or experiences of specialists who have, with more or less ability, investigated the subject.

While there is some difference in opinion as to the amount of air that ought to be admitted to any room or space to secure a sufficient dilution of impurities constantly accumulating, there is general agreement that total and continuous change of all the air is desirable for comfort, and necessary on the score of health. We may briefly refer to some of the best and well known writers on ventilation, and in doing so examine the conceded requirements for general and healthy conditions.

We have seen that there are many writers that estimate the amount of air required for different individuals, sexes, ages, and conditions at *six hundred to twelve hundred* cubic feet per hour, while others stop not short of *fifteen hundred to three thousand*. Confining this estimate now to school buildings, we may notice that the difference is a matter of 100 per cent.

Taking the case of existing buildings, and where no special or proper provision has been made for ventilation, we may conclude at once that the heating apparatus which is only sufficient to keep those buildings from freezing up will not avail for the large additions of duty which efficient ventilation demands.

In other words, many writers pass at once from a state of no regular or visible supply to that of the largest which talent or money could command. This passage from the most extreme poverty [illegible] wealth and lavishness in the matter of a pure air supply. [illegible] from one point of view, is also liable to delay, if not [illegible] desired reform.

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* See page 522.

THE WARMING AND VENTILATION OF SCHOOL BUILDINGS.

* "The schoolhouses throughout the United States, while they are elegant, tasteful, and costly, are in the main deficient in their sanitary requirement of warming and ventilation. Whoever may be disposed to doubt the truth of this statement has but to visit the nearest schoolhouse. Probably in nine tenths of all the schoolhouses in this country, ventilation has been ignored altogether, leaving that important function to be performed by the doors and windows. *But ventilation should be independent of doors and windows*, which are primarily intended for other purposes. How many school-rooms in the land could maintain a school with doors and windows made air-tight? Probably very few. It is a sad travesty on our school architecture that we owe our lives to the mistakes of carpentry, which mistakes are usually sufficiently ample to supply in a crude, unwholesome way the deficiencies of ventilation.

"The careful teacher, instructed in anatomy, physiology, and hygiene, as required by our legislators, recognizes the necessity of pure air, and ventilates by raising the windows, or lowering them at the top, the popular fancy being that bad air ascends. *Thus injurious draughts are created, and, by choosing a lesser evil, sacrifices the few children who sit near for the benefit of the many in distant and more sheltered parts of the room.* If any one unconversant with the subject doubts the assertion that, as a rule, school-rooms are not well ventilated, let him spend one day in school visitation; he will find then abundant evidence. It will not be necessary to use instruments of precision, or make chemical analyses to calculate to a nicety the amount of deleterious substances in each cubic foot of air; on the contrary, his sense of smell will at once warn him of the danger if he remains long in the contaminated atmosphere.

"The want of sufficient and definite information regarding the ventilation of schoolhouses is not peculiar to any locality; it is wide spread and general. Even the District of Columbia, which is under the direct control of the Central Government, experiences the embarassments which this all important but vexed problem presents. By a resolution of the House of Representatives, dated Feb. 20, 1882, a commission was appointed for the purpose of investigating the public-school buildings of the District of Columbia. *The principal defect from a sanitary point of view, in all these buildings*, is in regard to the fresh-air supply, which is entirely insufficient."

This report has not been quoted from to show the best that has been done in schoolhouse ventilation, but rather what may be considered a fair representation of the average state of affairs.

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* Gilbert B. Morrison, "Ventilation of School Buildings," 1887, D. Appleton & Co., New York.

"Direct experiments, no less than the direct evidence of the senses, prove that the air in our schoolrooms is impure in almost all cases, and in the majority of them to a degree far beyond the danger line.

"In view of these facts, and the results, as proved by the authorities above cited, why is it regarded by the public with such indifference? When a schoolhouse is blown down by a hurricane, killing and maiming a score of children, it is justly regarded as a great calamity; a vacation is given to quiet the excited fears of parents and children; investigating committees are appointed to locate the responsibility, and the faces of the whole populace are blanched with apprehension.

"Why does the intelligent parent send his child to a schoolroom poorly ventilated and crowded with children, some of whom are breathing into a stagnant air the germs of disease and death, while others, from unwashed bodies, are delivering into it their deadly emanations, and all without a protest on the part of those even who provide proper hygienic conditions at home? It is because the effects of one are immediate, occupy little time, the number killed can be actually counted, and the exact magnitude of the calamity be estimated all at once. In the other case the process is slower, but of far greater extent; the actual results are by the general public less definitely known, and custom and attention to other matters divert the attention, and the deadly destruction of the innocents by impure air goes on silently, constantly, and powerfully.

"While noisy demonstrations like that of the cyclone attract attention, and inspire fear and terror, it is in the silent forces that the danger lies. Nature's most destructive forces, as well as her strongest constructive ones, are silent in their operations; but, when Science detects a silent, insidious enemy to human welfare, it is not only our duty to assume an attitude of self-defence and self-protection, but it should be regarded as folly not to do so. Could the real effects of breathing impure air be realized by the public, and the actual amount that is really breathed be definitely known, such a knowledge would constitute a most powerful stimulus toward solving the problem of ventilation, as well as create a disposition to provide the means necessary thereto.

"'The condensed air of a crowded room,' says one of our first chemists, 'gives a deposit, which, if allowed to remain a few days, forms a solid, thick, and glutinous mass, having a strong odor of animal matter.'

"Dr. Hiller, Secretary of the Metropolitan Medical Association, says: 'In consequence of the bad construction and bad ventilation of the schoolhouses about London, seven thousand children, between the ages of five and fifteen years, annually lose their lives from the causes alone.'"

*"Every observing teacher knows the immediate relation between the vitiated air in the schoolroom and the work he wishes the pupils to perform. Much of the disappointment of poor lessons and the tendency to disorder are due directly to that cause. The brain unsupplied with a proper amount of pure blood refuses to act, and the will is powerless to arouse the flagging energies; the general feeling of discomfort, dissatisfaction, and unrest, which always accompanies a bad state of the blood, breeds most of the schoolroom squabbles, antagonism, and misunderstanding, and dislike which are wont to occur between teacher and pupil. The pupil, apparently at variance with his teacher, is really at war with his own feelings, caused by an impure and stagnated condition of the blood. The teacher, who sometimes thinks the pupils are all conspiring against him, and who with dizzy and clouded brain says the wrong thing at the wrong time, is really struggling with the poison, which, on account of his long seclusion from the cheerful air, has taken possession of him. Teachers observe how much more satisfactory is the work of the first hour of the day than that of any subsequent hour; this is not because of any weariness of the pupils; it is because they are made stupid and obtuse, and the teachers made uneasy and fretful, by the accumulating poisons from skin and lungs.

"From an economical standpoint it would, of course, be impossible to estimate the financial waste of breathing impure air, but it cannot but be enormous. In a comfortable atmosphere of proper temperature and purity as much mental labor can be accomplished in one hour as can be accomplished in six in an atmosphere rendered impure by respiration. This is, of course, but a random estimate; but I am quite sure that whatever of error it contains is on the side of underestimating the deteriorating influences of impure air, rather than of overestimating the value of pure air. If, then, we suppose perfect ventilation possible, and that this estimate is not overdrawn, the conclusion follows that in those schoolrooms where ventilation is imperfect, and the air impure, six tenths of the money expended to educate a child is wasted. Doubtless this will appear to some as an exaggerated statement; but if we accept the premises the conclusion is inevitable.

"This conclusion supposes that perfect ventilation costs no more than imperfect or no ventilation; while this is not strictly true, the difference is insignificant when compared with the loss we are considering. In any discussion of the feasibility of incurring the additional expense of the most perfect ventilation, the loss occasioned by the want of such ventilation must not be ignored.

"The fact that good ventilation is expensive is not so well recognized as it should be, as much of our literature on the subject is furnished by English authors who write with reference to the climate of England."

*Gilbert B. Morrison.

*"The tender, sensitive child, that sits and reads, and learns his lesson, and stupefies, and pines, and droops, and maybe has scarce a smile to expect when his task is done, yields day by day to his atmospheric foes. Day by day, and as he loses the first start in life, his lungs play less freely, his blood circulates more slowly, his chest contracts and his limbs pine away, his digestion is disordered, and before long he is delivered over to the tender care of the man who gallops in every other day, sends whole bales of pills and draughts, and soon settles either the life or constitution of his unfortunate patient.

"It is needless to urge that danger to the health and life of the child is so remote and trifling as to be unworthy of consideration. The reverse is the case. Instances are constantly occurring in which the seeds of disease are gathered in the close and polluted air of the schoolroom to ripen into premature decay and an early death. Many parents can call to mind the frequent complaints of their children who have returned from schoolrooms, feverish and pale, laboring under a depression of spirits and lassitude of body. A passing emotion of compassion may have attributed their appearance to confinement and study, neither of which is productive of evil effects, unless accompanied by an atmosphere rank with impurity, habits opposed to cleanliness and health, and a loss of comfort and necessary recreation.

"In a schoolroom with no means of ventilation, and containing from fifty to one hundred scholars, the air breathed by each different pair of lungs loses its vital properties, and becomes loaded with the impurities and infections thrown off from numerous systems. To contend that there is in this no danger to health of the child, is folly. The temporary symptoms of suffering may disappear with the habit which occasioned them; but the tendencies of disease linger in the system, awaiting some predisposing cause to develop their active strength and hurry their victim to an untimely grave.

"These statements are no exaggeration of the evil, for exaggeration is impossible. Still the evil is allowed to exist, because its first manifestations are not in a form that appalls and terrifies. Its approach is slow and insidious; the operation proceeds in secret. At length, the frame, racked with pain, a mind debilitated, unbalanced or diseased, powers of usefulness or enjoyment destroyed, are the fatal results of a few years spent in a crowded and heated schoolroom. For all these consequences the prevention is of the simplest character. The most ordinary mechanical contrivance will secure pure air to [illegible] child and happiness to the man.

"*That is a costly economy which sacrifices soun* [illegible]
the danger of disease to save a trifling expense."

* Henry Ruttan.

SANITARY CONDITION OF SCHOOLHOUSES.

BOARD OF HEALTH, 12 BEACON STREET, BOSTON, Oct. 10, 1889.

TO THE HONORABLE CITY COUNCIL,—

"*Gentlemen:* In response to an order of the City Council, received June 10, requesting the Board of Health to examine the schoolhouses of the city and report their sanitary condition, we beg to present the following statement and recommendations, a copy of which has been sent to the press:—

"The principal part of the work was done during the last few days, before the closing of the schools in June, but the number of pupils in each building was not obtained before the teachers had left the city for their vacations. This information was received only since the return of the teachers in September. Otherwise this report would have been made in June.

"We have examined 163 schoolhouses with the following results: Defective drainage was found in 35, want of traps in 7, offensive privy vaults in 51, offensive urinals in 49, offensive and defective cesspools in 15, offensive water closets in 6, defective rain conductors in 4.

"The ventilation of the buildings, the condition of the cellars, and the surrounding air-spaces were carefully examined and called for special remark. Fifty-seven of the cellars were *dark*, *musty*, or *damp;* 46 of the houses could properly be criticised as having too little yard-room, or air space, surrounding them, while some are closely hemmed in by high buildings or by objectionable trades.

"*Of the* 163 *houses examined,* 146 *are without any modern or efficient means of ventilation, being dependent upon the old-fashioned shafts in the wall, aided here and there by small apertures through the external walls, all of which is too feeble to be called ventilation.*

"In 11 of the schoolhouses the extraction of the foul air has been more or less promoted by the aid of heat applied to the outlet shafts, to increase the current of air, and in 6 *others the same object has been sought and more or less effected by the use of exhaust fans in the tops of the buildings.*

"It would be much better if all privy accommodations were removed from the cellars to an adjoining apartment, where ventilation and such use of water or heat for the disposal of excreta could be used as may be found most healthful and economical by expert calculation. A dry and light cellar would be largely promoted by this step, and what is now a possible danger would be altogether avoided.

"The question of yard-room and the surroundings of the schoolhouses is an important one, and should be carefully considered in giving the necessary sunlight and fresh-air currents about the building.

"The large number of pupils in each building and the lack of means for extracting the foul air have claimed the most attention, and constitute the greatest sanitary evil connected with our schools.

"In our recent examination, we find by measurement that the average number of cubic feet of space given to each pupil, in 163 houses examined, is as follows:—

Reckoned by the number of seats	202 cubic feet
Reckoned by the registered pupils	235 cubic feet
Reckoned by the average attendance	267 cubic feet

Ten of the best gave an average as follows:—

Reckoned by the number of seats	407 cubic feet
Reckoned by the number of registered pupils	504 cubic feet
Reckoned by the number of average attendance	559 cubic feet

Ten of the poorest gave an average as follows:—

Reckoned by the number of seats	90 cubic feet
Reckoned by the number of registered pupils	99 cubic feet
Reckoned by the number of average attendance	112 cubic feet

"These measurements were made by 12 inspectors, and, while there may be slight errors in individual cases, they may be regarded as too small materially to affect the averages given."

"In 1874 we caused to be made a chemical analysis of the atmosphere of every room in 10 schoolhouses. The selection of the houses and the methods pursued were such as to give a fair average of the condition of the air in all of the schoolhouses of the city, without needlessly extending the expense. The result of this examination showed that in only one room of the 111 rooms examined was the impurity as low as 5.7 volumes of carbonic acid gas to 10,000 volumes of air, and from this it ranged as high *as 30 volumes to the* 10,000. The rooms of the best house averaged 8.3 volumes to 10,000, and those of the poorest one 18 volumes to 10,000. The majority of the schoolhouses remain unaltered. Having ascertained the actual condition of the air in the average schoolroom, are we justified in saying that such an atmosphere is unwholesome and produces mental and physical lassitude in the children?

"An excess of carbonic acid gas in the air is regarded by authorities as indicating an excess of other impurities, and has been adopted as a standard measure in testing the purity of the air. The normal atmosphere contains about 4 volumes of carbonic acid gas in each 10,000 volumes of air; and, when the amount of carbonic acid exceeds 7 volumes in 10,000, the air becomes perceptibly vitiated, and cannot be regarded as suitable for respiration.

"We have found by measurement that the average air-space allotted to each pupil in the average schoolroom, with an average attendance, is 267 cubic feet, and when the seats are filled, 202 cubic feet.

"Now, if 3,000 cubic feet are needed for each pupil per hour, the amount given to start with will last from four to five minutes, and to be kept fresh must be changed from 12 to 15 times each hour. This is impracticable. In the poorer houses, or those in which the smaller spaces are given, the change of air by the same rule would need to be made about 30 times per hour.

"We have considered the amount of air supply found necessary for the best results. *Two thousand cubic feet per hour would be a compromise*, and not an unreasonable amount to ask for. Can this be done, and how?

"*The practicability of ventilating schoolhouses admits of no doubt. It is as much a matter of exact knowledge as any other question in mathematics or engineering. The air should be introduced into the room at a proper temperature, well distributed to the children, and removed sufficiently often to prevent foulness and without producing uncomfortable draughts. This can be done only with the aid of power, and may be accomplished by heated shafts or fans. The air may be propelled into the room and escape by properly arranged outlets, or the foul air may be extracted from the room having properly arranged inlets for the fresh air, preference being given to the latter method. All dependence upon natural ventilation should be abandoned as delusive and untrustworthy, and the simple question of expense, for the use of the necessary power to move the air, be recognized and met without further delay.*

"The Board of Health would respectfully recommend that His Honor, the Mayor, be authorized to appoint a board of three sanitary experts, who shall consider and report to your honorable body, within six months from their appointment, the best method and specifications for ventilating our schoolhouses, and of disposing of the excreta therefrom; and that for such services the experts be paid a liberal compensation."

Respectfully submitted, for the Board of Health.

Chairman.

Referred to the Committee on Schools an [illegible]

Commonwealth of Massachusetts.

DEPARTMENT OF INSPECTION OF FACTORIES, WORKSHOPS, AND PUBLIC BUILDINGS.

OFFICE, COMMONWEALTH BUILDING.

Boston, March 26, 1888

To whom it may concern:

CHAP. 149.

In the year One Thousand Eight Hundred and Eighty-eight.

AN ACT

TO CAUSE PROPER SANITARY PROVISIONS AND PROPER VENTILATION IN PUBLIC BUILDINGS AND SCHOOLHOUSES.

Be it enacted by the Senate and House of Representatives in General Court assembled, and by the authority of the same, as follows:—

SECTION 1. **Every public building and every schoolhouse shall be kept in a cleanly state and free from effluvia arising from any drain, privy, or other nuisance, and shall be provided with a sufficient number of proper water-closets, earth-closets or privies for the reasonable use of the persons admitted to such public building, or of the pupils attending such schoolhouse.**

SECT. 2. Every public building and every schoolhouse shall be ventilated in such a proper manner that the air shall not become so exhausted as to be injurious to the health of the persons present therein. The provisions of this section and the preceding section shall be enforced by the inspection department of the district police force.

SECT. 3. Whenever it shall appear to an inspector of factories and public buildings that further or different sanitary provisions or means of ventilation are required in any public building or schoolhouse in order to conform to the requirements of this act, and that the same can be provided without incurring unreasonable expense, such inspector may issue a written order to the proper person or authority, directing such sanitary provisions or means of ventilation to be provided, and they shall thereupon be provided in accordance with such order by the public authority, corporation or person having charge of, owning or leasing such public building or schoolhouse.

SECT. 4. Any school committee, public officer, corporation or person neglecting for four weeks after the receipt of an order from an inspector, as provided in the preceding section, to provide the sanitary provisions or means of ventilation required thereby shall be punished by fine not exceeding one hundred dollars.

SECT. 5. The expression "public building" used in this act means any building or premises used as a place of public entertainment, instruction, resort or assemblage. The expression "schoolhouse" means any building or premises in which public or private instruction is afforded to not less than ten pupils at one time.

SECT. 6. This act shall take effect upon its passage.

Approved March 20, 1888.

RUFUS R. WADE,
Chief Inspector of Public Buildings.

CONDENSED REPORT OF RUFUS R. WADE, CHIEF MASS. STATE SANITARY POLICE, DEC. 31, 1888.

"It would seem that there could be no misapprehension as to the scope of this act nor the exact meaning of its several sections. A public building or schoolhouse may not be in such a filthy or unwholesome condition as to call for the interference of the Board of Health; yet its ventilation may be radically bad, its drains and privies defective or foul, and its air laden with vile effluvia injurious to the health of the persons present therein.

"That such evils have long existed, will not be denied by any one conversant with the facts. Public-school teachers have made frequent complaints of defective drainage of schoolhouses and offensive odors arising from privies, which are placed in most cases near the buildings, and in other cases in the basement or cellar. The vile stenches arising therefrom are complained of, but not always is the remedy applied. Some makeshift is relied on to get rid of the complaint. It would shock and disgust parents to know what crude and defective arrangements for sanitary purposes are maintained in certain schoolhouses, where the ignorance or indifference of janitors and others in charge imperils health and life.

"It will be observed that section 1 declares that every public building and schoolhouses shall be kept in a cleanly state and clear of any effluvia arising from any drain, privy, or other nuisance, etc. That there are such buildings infected with such vile odors, which are offensive to the senses, if not immediately destructive to the health, we know from actual observation.

"From the foregoing we have felt justified in proceeding upon the assumption that the supply of fresh air to, and the removal of foul air from, our schoolhouses should not be less than *three thousand cubic feet per hour.*

"The wisdom of the act and the importance of its enforcement are made apparent from our investigation, which reveals a general deficiency in the matter of space allowed for scholars, and the provisions for a fresh and foul air removal in the schoolhouses of the State. From the reports of the inspectors I fail to find the standard reached even in the best-ventilated buildings of the city of Boston. And in a large number of the older buildings (especially those occupied by the primary department of the school), the deficiency is startling, the condition of the air being such that no test is required to prove its unfitness for respiration, and danger to the teacher and pupil occupying the building. In many buildings we find no provision even for fresh-air supply, and in others the supply is through the cold-air boxes leading to furnaces, where, as a rule, they are entirely inadequate and not unfrequently are partially or entirely closed. *In the class of buildings heated by steam, by what we call the indirect system, we find the best provision for air supply;* but even that, with scarcely any exception, comes far short of the standard adopted, and the supply for the different rooms is irregular, and materially affected by the condition and temperature of the wind outside.

"A very general and almost universal deficiency is in the size of the fresh and foul air flues, which are found so small as to require a very great velocity in order to accomplish the necessary work. To illustrate, it is rarely that we find more than two supply pipes in a room, and these are not over fourteen inches in diameter. To get the amount of air required for fifty-six pupils through these pipes would call for a velocity of **1,309** feet per minute, which is not obtained. The same deficiency exists in the foul-air flues, and it is not infrequently the case that the inspectors have found no movement of air whatever in these flues. In the annex to the Putnam School, Cambridge, built in 1887, it was found that the ventilating flues were 5 inches x 24 inches, or 120 square inches; that the velocity of the air was only 150 feet per minute. The size of the room was 31 feet 6 inches x 28 feet x 12 feet; the number of scholars 50, *giving but 2½ cubic feet of air per minute to each scholar, against* 50 *cubic feet per minute that should be given them.*"

VIEWS OF DIFFERENT INSPECTORS OF MASS. DISTRICT POLICE.

REPORT OF 1888.

Inspector Coon reports: "During the present year I have made examination of many public buildings in my district, more particularly those occupied as schoolhouses, and to my astonishment have found results little anticipated. One would suppose that in the present age such a thing as bad sanitation about a shoolhouse, 'owned and supported by public taxation, under the control of local authorities, whose duty it is to see that proper safeguards are thrown about our children,' would not be tolerated; but the fact is, it does exist, and many of the schoolhouses and their surroundings are found in an extremely bad condition.

"The public should know of the unhealthfulness and discomfort of the building wherein their children spend so many hours of their lives, and the errors and faults in buildings, and their sanitary construction, owing to the unconcern of those in charge in matters of such vital importance; the neglect of incompetent janitors, who seem to be under no obligation, 'in the care of the building,' to master, teacher, or pupil, but hold a lordly sway, especially when in charge of a building whose teachers are females. The janitor who cares best for his building, and keeps it in a clean and healthy condition, is the one who will consult the interest of the teachers and endeavor to please them, and will discharge his duty in an acceptable manner."

Inspector Brown reports: "In every schoolroom that I have thus far inspected, most of the ventilation is obtained by opening doors and windows, the ventilating shafts being too small to be of much benefit; and the janitors are, as a rule, a further hindrance to ventilation, as I usually find the air inlets in the basement entirely closed, sometimes a small part open, and at times taking the air only from the basement, instead of the pure air from outside the building. *This ventilation of schoolrooms I consider of the most vital importance, and the great want of ventilating arrangements cannot be too strongly deplored.*"

Inspector Dyson reports: "Sanitary and ventilation experts and others differ, but almost all agree that the air in a schoolroom *should be changed every fifteen minutes,* and that there should be supplied no less than fifty cubic feet of fresh air per minute for each scholar, to provide proper ventilation. With these facts, and knowing that a large majority of our schoolhouses *have no system of ventilation at all,* many of them with unheated ventilating flues with openings in the ceiling or near the top of the room, are more likely to give a downward than an upward draught. Even the modern houses, provided with what is called the best system of ventilation, rarely provide more than ten cubic feet of fresh air per scholar, and *I have found but one room that gave twelve cubic feet per minute. The question arises where to begin and what system to adopt.*"

Inspector Dexter reports: "The schoolhouses in my district are provided with some means by which it was intended proper ventilation should be had in each room in the building. The method in most common use is by means of one or more small flues in each room (from which there is an opening into the room) leading to the attic. The bad air from the schoolrooms is conducted to the attic through these flues, from whence there is no escape for it except through cracks in the roof or walls of the building, and as a consequence it is returned to the rooms again by other flues. In other cases the ventilating flues connect with a brick chimney built for the purpose; and in some cases the chimneys which furnish draught for the furnaces are of iron, and are enclosed in the ventilating chimney. *But in every case the ventilation is insufficient, and the windows have to be resorted to to supply the deficiency; more especially is this the case where the building is heated entirely by direct steam radiators.*"

Inspector Chadwick reports: "As to the question of ventilation and the sanitary condition of schoolhouses, we find in many a lamentable lack of favorable conditions; more so in the schoolhouses than in the workshops and factories; often a room arranged for 60 to 70 pupils has an allowance of only 150 cubic feet of air space for each pupil, and depending almost entirely upon the windows for air."

SPECIAL EXAMPLES.

GASTON SCHOOL BUILDING, SOUTH BOSTON.*

"*This building is heated by steam, indirect radiation.* The arrangement for fresh-air supply to the coils is very good. Openings in brickwork to coils might be enlarged to good advantage, to allow a larger volume of air to pass. On the day of my visit only one boiler was in use in the building, so could get no fair test of fresh-air supply. Four foul-air stacks are provided in the building, about 4 feet x 5 feet 4 inches, each having steam coils near the top above all flue inlets. These stacks are connected in the attic of the building with galvanized iron pipes, 3 feet in diameter, to ventilators on the roof. Only one stack had steam on it at the time of my visit. The velocity of the foul air out through these 36-inch pipes was 420, 410, and 360 feet per minute, respectively, making a total discharge from the building through the foul-air shafts of 708,360 cubic feet per hour. In colder weather, with all steam on, the results would doubtless be materially improved. This building will accommodate about 784 pupils.

"*A provision of 3,000 cubic feet of air per pupil per hour would call for an air movement of 2,352,000 cubic feet per hour. Each pupil receives* $15\frac{5}{16}$ *cubic feet of air per minute, in place of 50 cubic feet that each should receive. This is considered one of the best-ventilated school buildings in the city of Boston.*"

CARTER SCHOOL BUILDING, CHELSEA.

"*This building is heated by furnaces;* scarcely any fire in them; conditions not favorable for taking fresh-air supply. All that is provided, *except by opening of the windows*, comes through the cold-air boxes to furnaces, which are entirely inadequate. Foul-air flues and registers *entirely too small*, the registers being 8 inches x 10 inches, and 10 inches x 14 inches in rooms provided for 56 pupils. Found average discharge of foul air through registers in lower rooms to be 6,300 per hour each; second floor, 7,950 cubic feet per hour each room; third floor, 7,380 cubic feet per hour each room; fourth floor, 8,520 cubic feet per hour each, making a total of about **103,560** cubic feet per hour.

"*A provision of 3,000 cubic feet per hour per pupil for 784 pupils would call for an air movement of* **2,352,000** *cubic feet per hour. Each pupil receives* $2\frac{3}{16}$ *cubic feet per minute, in place of 50 cubic feet, the usual allowance.*"

BLOOMINGDALE SCHOOL BUILDING, CHELSEA.

"*This building is heated by steam-pipe radiators in two of the corners of each room.* To the larger of these an 8-inch pipe, and to the smaller a 6-inch pipe, are provided to bring a fresh-air supply from outside the building; but the movement of air through them was scarcely perceptible. This is all the provision (about 79 square inches area) for fresh air to each of the rooms provided for 56 pupils. The pipes above mentioned are connected with registers on the outside of the building, which are rusty and inoperative; one of which, being measured, presented an opening of only about 17 square inches, to supply a pipe of 50 square inches area. The foul-air registers are 12 inches x 18 inches. In three of the rooms the velocity of air passing out was found to be 190 feet per minute, and in one of the rooms 150 feet per minute; the total amount of foul air removed from the building through the registers being **43,200** cubic feet per hour.

"*An air supply of 3,000 cubic feet per pupil per hour would call for an air movement of* **672,000** *cubic feet.* Windows resorted to for fresh-air supply. *Each pupil now receives* $12\frac{5}{16}$ *cubic feet per minute, in place of 50 cubic feet that each ought to receive.*"

BROADWAY SCHOOL BUILDING, CHELSEA.

"This is a four-room building provided for 270 pupils, *heated by steam, direct radiation;* steam pipes run about the sides of the rooms. This building *has no provision whatever for fresh-air supply*, except what may be secured by opening the windows. *No movement of air through the foul-air registers.*"

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* See accompanying table of conditions, page 519.

The foregoing papers relating to the action of the Senate and House of Representatives and the reports of the Chief of the District Police and Board of Health, are introduced as the best answer to many questions regarding the law and the application of it to the special class of buildings under consideration. Similar laws have been passed by some other States.

The revised charter of the city of Rochester, N. Y., 1877, created a Board of Health with more extended authority than that exercised by previous boards, and among other items the new board has authority to regulate the heating and ventilation of public schoolhouses throughout the city. Under their power the board appointed an examiner to look into the condition of schoolrooms, and some startling revelations were the result. But as the examiner had personal power to act only by report and recommendation to the board, we may easily see that the reform and relief would come slowly if at all, since "the knowledge of an abuse is one thing, the efficient and prompt remedy of it another." The Massachusetts law before referred to (page 514) not only confers the power to issue mandatory orders, but prescribes the penalty for disregarding them. The apathy manifested on the subject of ventilation by those charged with the erection and care of buildings is simply astounding! Ignorance of any subject or science may rest lightly on any individual, when the results, although disastrous, fall only on those who break and defy the laws. That even such a course is reprehensible, we need not stop to prove; but what shall be said of the men or set of men who, from whatever motive, have accepted the responsibility of providing for the health, comfort, and prosperity of hundreds of their fellow human beings, who either do nothing worthy of the name, or carelessly turn over the whole matter to others more ignorant than they themselves?

It was reserved, however, for the town of Revere, or rather its School Committee, to resist the efforts and orders of the inspectors to furnish their school buildings with a proper air supply. Carried into court and shown up as resisting a sanitary law and ignoring the attending dangers to the children, they took refuge behind a defective service and a local judge, who ruled that the case of the State was not *proven.**

That such a board of sanitary police has onerous and delicate duties, is clear, and that even with the law clearly defined there may be no little difficulty in inaugurating reforms and in securing a proper air supply under the various and conflicting conditions.

*NOTE.— In justice to the committee and the court, it should be stated that the judge, while declining to rule against the School Committee, remarked on the singular and apparent deficiency of a pure air supply to these schools, and advised the committee to take action on the matter. This they did later, and voted $3,000 to improve the ventilation in their several school buildings.

EXAMPLES OF SCHOOL VENTILATION.

From the Report of the Chief of the Massachusetts District Police for the year ending December 31, 1888.

TABLE No. 24.

No.	NAME OF SCHOOL AND LOCATION.	METHOD OF HEATING.	No. of Class Rooms.	Aver. No. of Pupils in each Room.	Aver. air Space per Capita.	Cubic feet of Air supplied to each Pupil per Hour.			REMARKS ON VENTILATION.
						Min.	Max.	Ave.	
1	Broadway, Chelsea.*	Steam, Direct..........	4	68	149	0	0	0	No provision for fresh air except by windows.
2	Drury Acad, N. Adams.*	Steam..................	19	49	221	0	86	....	Only means of changing the air by windows.
3	Bridge St., Springfield.	Furnace, Hot-air.......	3	36	246	0	88	...	Registers all open to one flue, containing smoke stack.
4	Grant, Watertown.		....	....	....	—	72	....	Rooms supplied with "window boards."
5	High, Pittsfield.	Steam..................	4	81	194	90	162	....	Ventilating registers, 10 x 13 in., opening into smoke flue.
6	Bay St., Taunton.	Furnace, Hot-air.......	8	71	192	53	320	....	Ventilated by small ducts and windows.
7	Carter, Chelsea.*	Furnaces, Hot-air......	14	51	230	....	....	132	Registers, 8 x 10 inches and 10 x 14 inches.
8	Davenport, Fall River.	Hot air................	15	46	251	150	210	....	Ventilated by small ducts and windows.
9	Adams Academy, Adams.	Furnaces...............	10	46	280	198	205	....	Ventilator openings, 10 x 15 in.; obstructed, 10 x 10 in.
10	Central Grammar, Pittsfield	Steam..................	2	120	222	191	214	....	
11	New Webster, Camb'port.	Furnaces...............	17	49	180	....	....	246	Brick flues and open fire places.
12	Morgan St., Fall River.	Steam, Direct and ind..	10	48	230	....	....	255	Ventilated by small air ducts and windows.
13	Webster St., East Boston.	Furnaces...............	6	55	143	....	371	....	Inlet reg., lower floor, 196 in. net; outlets, 10 x $12\frac{5}{8}$ in.
14	High, Charlestown.	Steam, Indirect........	6	63	288	....	613	...	Foul-air flues terminate in chamber in attic.
15	Cohannet St., Taunton.	Hot air................	10	57	183	285	353	....	Ventilated by small ducts and windows.
16	High, Northampton.	Steam..................	10	47	215	....	....	364	Each room has a ventilating flue.
17	Borden, Fall River.	Steam, Direct and ind..	6	43	294	....	....	390	Ventilating flues open into cellar.
18	Brownell St., Fall River.	Hot air and steam......	4	48	250	....	....	420	Ventilating flues open into attic with vent. tower.
19	Highland, Lowell.	Steam, Direct..........	8	54	230	....	....	420	Foul-air flues, 22 x 30 in.; openings only 19 x 19 in.
20	Elm St., Springfield.	Steam..................	12	45	254	....	463	....	No ventilation without using windows.
21	Freeland St., Worcester.	Steam..................	8	53	207	181	642	464	Ventilated by steam-heated flues.
22	Davis, Fall River.	Hot air and steam......	12	50	273	345	780	....	Ventilated by small ducts and windows.
23	Lyman, East Boston.	Steam, Indirect........	14	56	227	497	769	....	Area of inlet registers, 334 inches; outlet, 405 inches.
24	New Ledge St., Worcester.	Ruttan-Smead furnaces	6	54	171	587	727	662	Ventilating shaft with heat at the base.
25	Old Ledge St., Worcester.	Ruttan-Smead furnaces	9	51	206	657	817	722	" " " " " " "
26	Robeson, Fall River.	Hot-air furnaces.......	6	61	183	650	1065	....	Currents variable in some flues.
27	Cabot, Brookline.	Steam..................	....	....	....	583	1478	....	Two flues, one containing smoke stack from boiler.
28	Bloomingdale St., Chelsea.*	Steam, Direct and ind..	4	56	192	....	....	768	Area of cold-air ducts, 79 sq. in. Foul-air reg., 12 x 18 in.
29	Gaston, South Boston.	Steam..................	14	55	226	....	....	930	Foul-air stacks, 4 x 5 feet 4 in. Steam coils near the top.
30	Joshua Bates Prim., Boston	Steam..................	8	56	168	....	....	....	Blackman exhaust fans, ventilation comparatively good.
31	Bay St. (new), Springfield.	Hot water, Mills system	8	45	220	600	1200	900	Good draught caused by fan in the attic run by water. Area (net) of registers, 214 inches.

*Ventilation Improved, 1889.

*METHOD OF ESTIMATING THE AIR REQUIRED.

"Under the general conditions of outdoor air,— namely 70° of temperature and 70 per cent of complete saturation,—an average adult man, while sitting at rest, makes 16 respirations per minute of 30 cubic inches each, or 480 cubic inches per minute. Under the previously assumed conditions of temperature and humidity, the air thus inhaled will consist of about $\frac{1}{5}$ oxygen and $\frac{4}{5}$ nitrogen, together with about $1\frac{7}{10}$ aqueous vapor and $\frac{4}{100}$ of a per cent carbonic acid. By the process of respiration, the air will, when exhaled, be found to have lost $\frac{1}{5}$ of its oxygen by the formation of carbonic acid, which will have increased one hundred-fold, thus forming 4 per cent, while the water vapor will be about 5 per cent of the volume. In addition, the inhaled air will have been warmed from 70° to 90°, and, notwithstanding the increased proportion of carbonic acid,—which is $1\frac{1}{2}$ times heavier than air,—will, owing to increase of temperature and the levity of the water vapor, be about 3 per cent lighter than when inhaled. In addition to the carbonic acid exhaled in the process of respiration, about $\frac{1}{5}$ more is given off by the skin. Assuming that an amount of air is supplied sufficient to dilute this to the same proportion as the breath, then obviously about 580 cubic inches, or .33 cubic feet, of pure air are actually required to supply the fixed requirements of the body. But furthermore, $1\frac{1}{2}$ to $2\frac{1}{2}$ pounds of vapor are daily evaporated from the surface of the skin by a person in still life. If the air supplied at 70° is assumed to have a humidity of 70 per cent, and to be saturated when it leaves the body at a higher temperature, then at least 4 cubic feet of air per minute will be required to carry away this vapor.

"Taking into consideration these various factors, it becomes evident that about 4 cubic feet of air will be required per minute to remove from an individual all vitiated air, and to furnish fresh air for respiration and the absorption of moisture from the skin. *This, however, is only on the assumption that any given body of air, after having fulfilled its office, is immediately removed without contaminating the surrounding atmosphere.* But from previous considerations, it is seen that the spent air from the lungs is immediately diffused into the atmosphere, and further that the carbonic acid allowance in indoor air should not exceed 6 or 7 parts in 10,000, whereas that in the .33 cubic feet of vitiated air removed from the person per minute, is present in the proportion of 400 parts in 10,000.

"*To dilute this .33 cubic feet, so that the carbonic acid shall not exceed 6 to 7 parts in the 10,000, there would be required about 19 to 22 cubic feet of air per minute, or about 1,140 to 1,320 cubic feet per hour, to secure healthy sanitary conditions.*"

*B. F. Sturtevant circular of 1884.

*For *schools*, according to Morin: Infant, 530; adult, 1,060; all agree, however, that this amount should be largely increased for different *places, uses, and conditions.* Hospitals, theatres, and assembly rooms require as much as 2,000 to 3,000 cubic feet. See page 522.

†"The amount of supply for audience halls should in no case be less than 30 cubic feet of air per minute through the regular flues of supply, and in legislative buildings the apparatus should be such that at least 45 cubic feet of air per person per minute can be furnished, with a possibility of increasing it to 60 feet per minute when desired. In dealing with such matters as air and water supply, engineers should endeavor to secure maximum and not minimum quantities.

"I am quite sure that no architect or engineer would advise making plans to correspond with the requirement of 10 cubic feet per minute per person, if the question of expense of construction and maintenance did not come in; and the difference between the opposing views is, in the main, that one considers the question of cost as more important than others are disposed to do.

"So far as construction is concerned, the difference in cost between providing for an air supply of 10 and one of 60 cubic feet per minute will not often be so great as to be a serious objection, *provided the plans be made before the construction of the building is commenced.*

"It is when we have to provide heating and ventilating arrangements for existing buildings that have been planned in utter ignorance of the requirements of heating and ventilation — and this is the case with at least one half of the largest and most costly buildings in New York — that we have to diminish the supply of fresh air to the smallest permissible amount in order to be allowed to introduce any at all.

"The ventilation of such buildings cannot be made satisfactory; it is only 'endurable,' and a ventilation which is only just 'endurable' is discreditable to the architect of the building in which it occurs, provided that his advice has been followed on this point.

"When it comes to the planning of such a building as a public school, I consider it to be the duty of an architect, not only to advise, but to insist on proper arrangements for heating, ventilation, and plumbing; and if it is his misfortune to have to deal in this subject with ignorant committee-men, who, with a limited appropriation for the purpose, insist in omitting, for the sake of cheapness, some of these points in construction which are essential to keeping the building in proper sanitary condition, it will be his duty to decline to have anything to do with the matter rather than to suffer himself to be used as a tool to execute work which he knows will be dangerous to the health and life of the children of his fellow-citizens."

* See full table of authorities and examples.

† Dr. John S. Billings.

TABLE NO. 25. VENTILATION.—CASES IN PRACTICE.

KIND OF BUILDING.	Cubic feet of air per head per hour.			OBSERVER OR AUTHORITY.
	Max.	Min.	Mean.	
Hospital. Guys, night	......	......	900	Mr. Rosser.
" " day	3960	2220	3090	" "
" Lariboisière	3950	2000	2975	M. Grassi.
" Necker, summer, entry	......	......	2084	MM. Combes, Leblanc, etc.
" " winter, entry	......	......	3108	" " " "
" Beaujon	......	......	530	Morin (sensible odor).
" "	......	......	880	" (odor disappeared).
" Vincennes (military)	4240	......	......	" (too much air, draughts).
" " "	......	......	2120	" (satisfactory).
Theatre du Palais Royal	......	......	636	M. Darcet.
" Lyrique (per seat)	1480	1150	1315	M. Morin.
" de la Gaité	1327	925	1126	" "
Prison, Cellulaire, Mazas	......	212	......	M. Péclet, etc. (sensible odor).
" " de Tours	918	530	724	M. Sagey. [sible).
School, 120 children, Grenelle	......	83	......	Morin (bad odor, very sen-
" 80 " "	......	......	120	" (bad odor, but slight).
" 76 " "	194	......	......	" (very little odor).
" 180 " 7 to 10 years old	......	......	212	Péclet (very slight odor).
Salle des Séances de l'Institut	1050	996	1023	M. Cheronnet.
Chambre des Pairs	706	424	565	Gay-Lussac, Pouillet, etc.,
Conservatoire des Arts, etc	530	353	442	Morin. [odor).
Ancienne Chambre des Députés	......	......	635	Péclet (satisfactory, no

AMOUNTS OF AIR REQUIRED BY DIFFERENT AUTHORITIES.

KIND OF BUILDING.	Max.	Min.	Mean	Observer or Authority.
Hospitals	.....	.....	2120	Péclet
Theatres, assembly rooms, etc	.....	.....	530	"
Prisons	.....	.....	350	
Ordinary rooms	390	212	300	
Schools	.....	.....	212	
Hospitals, ordinary maladies	.....	.....	2470	Morin
" wounded, etc	.....	.....	3530	"
" in times of epidemic	.....	.....	5300	"
Theatres	1760	1410	1585	"
Assembly rooms, prolonged sit.	.....	.....	2120	"
Prisons	.....	.....	1760	"
Workshops, ordinary	.....	.....	2120	"
" insalubrious	.....	.....	3530	"
Barracks, during the day	.....	.....	1060	"
" " " night	.....	.....	1760	"
Schools, infant	706	530	618	"
" adult	1410	1060	1235	"
Stables	7060	6350	6700	"

Miscellaneous Authorities.	No. of cubic feet for each person per hour.	
	Min.	Max.
Chas. Hood	210	600
Dr. Reid	......	600
Dr. Arnott	900	1200
Dr. Billings	1800	3600
Prof. Morrison	2000	3500
T. Schumann	......	2800
De Chaumont	......	4000
Dr. E. Parker	......	3600
H. Ruttan	420	600
G. B. Rafter	......	2000
Robt. Briggs	600	1800
W. Butler	215	283
J. Greenleaf	1800	3600

DEMAND FOR VENTILATION FOR PERSONS IN DIFFERENT CONDITIONS OF HEALTH, Etc.—THOS. BOX.

CHARACTER OF OCCUPANTS.	CUBIC FEET OF AIR FOR EACH PERSON PER HOUR.				
	For Respiration.	For Vapor.	For Exhalation.	For Heat.	For Lights.
Room with single occupant—cleanly and healthy	22	237	250	220	60
Room with single occupant—healthy, but not cleanly	22	237	350	220	60
Room with single occupant—cleanly, but sick.	22	237	1000	220	60
Crowded room—healthy and cleanly persons.	22	237	250	500	60
Hospitals (ordinary cases)	22	237	2000	220	60
Hospitals for fevers, etc	22	237	4000	220	60

SCHOOL NO. 10, DELAWARE AVENUE.

BUFFALO, N. Y., June 16, 1886.

MR. J. H. MILLS,—

Dear Sir: Herewith I send you a copy of the reports of heat in the several class-rooms of School No. 10 during the month of February past, the house being warmed by your combined system of steam and water, and the change of air being effected by your *mechanical method of a fan located in the attic, and driven by a water motor in the basement.*

I am also happy to comply with your request for my opinion of this simple yet efficient method of warming and ventilating schools and public buildings.

You will doubtless remember that at first I had not a large faith either in steam heat or a system of ventilation. I had not seen it in operation. Now I can speak from experience and use of the apparatus during the past three winters.

Of the temperatures you have a report, taken four times a day during February from each of the twelve class-rooms, and signed by the several teachers.*

Of the system in general, I may say I approve of every detail, from the employment of water circulation in the indirect radiators, through which the building is supplied with pure air, to the exhaust fan in the attic, which constantly and efficiently removes the large volume required.

From the tests made by the Superintendent of the New York Exhaust Ventilator Company (Mr. Strangland), it appears that when the fan is moving only 60 revolutions per minute, the velocity of the air is 600 feet per minute. The discharge outlet of the fan being 14 square feet, we have 8,400 per minute, or 504,000 cubic feet per hour, removed from the 12 rooms as follows:—

The four class-rooms on the *first* floor are 26 x 31 each, 9,728 = 38,912; *second* and *third* floors, 77,812, or 116,724 cubic feet in the 12 rooms; add for clothes closets connected with the ventilating apparatus 30,000 cubic feet, and we have 146,724 cubic feet. Dividing this 140,000 by 504,000,—the number of cubic feet of air moved by the fan,—we have the entire air of the rooms and closets changed every 17 minutes; or, the average attendance being 500, we have 1,008 cubic feet of air per pupil per hour.

I am aware that some writers advise a larger supply, as much as 1,500 *or even* 2,000 *cubic feet per hour per pupil; but I am convinced that it is possible to get too much of even a good thing, and that* 1,000 *cubic feet of air per hour per pupil fills every reasonable requirement on the score of health, and certainly on the score of comfort, since a greater supply could hardly be introduced without creating unpleasant draughts, to say nothing of the excessive fire required to warm so great a volume from the temperature of the outside air, the air being discharged at* 65°.

With the supply and removal of the amount first stated, we have not perceived the slightest trace of any odor, even after the longest sessions, while the entire absence of cases of headache or illness, so common with other systems of heat and imperfect ventilation, convinces me that we have at No. 10 *reached the happy medium so long desired for school ventilation.*

I would also mention with explicit favor the employment of water heat or circulation for the indirect system, by which it is possible to have the rooms tempered in the early fall and spring, doing without the common drawback of overheating, also the comfort of having a supply of warm water at the sinks for the cleaning of floors and windows.

As you desired, I have inquired as to the fuel burned, and find that the coal for the whole year is 120 tons. The total space in the building is 240,000 cubic feet, and, for say the 175 days that the building was under heat, we have .685 tons of coal per day, or 1,371 pounds at $4.50 per ton, equal to $3.02 per day of 24 hours, or 1,000 cubic feet is warmed and ventilated for 1¼ cents.

EUGENE E. FISH, *Principal of School No.* 10.

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* See diagram of temperatures, No. 23, page 453.

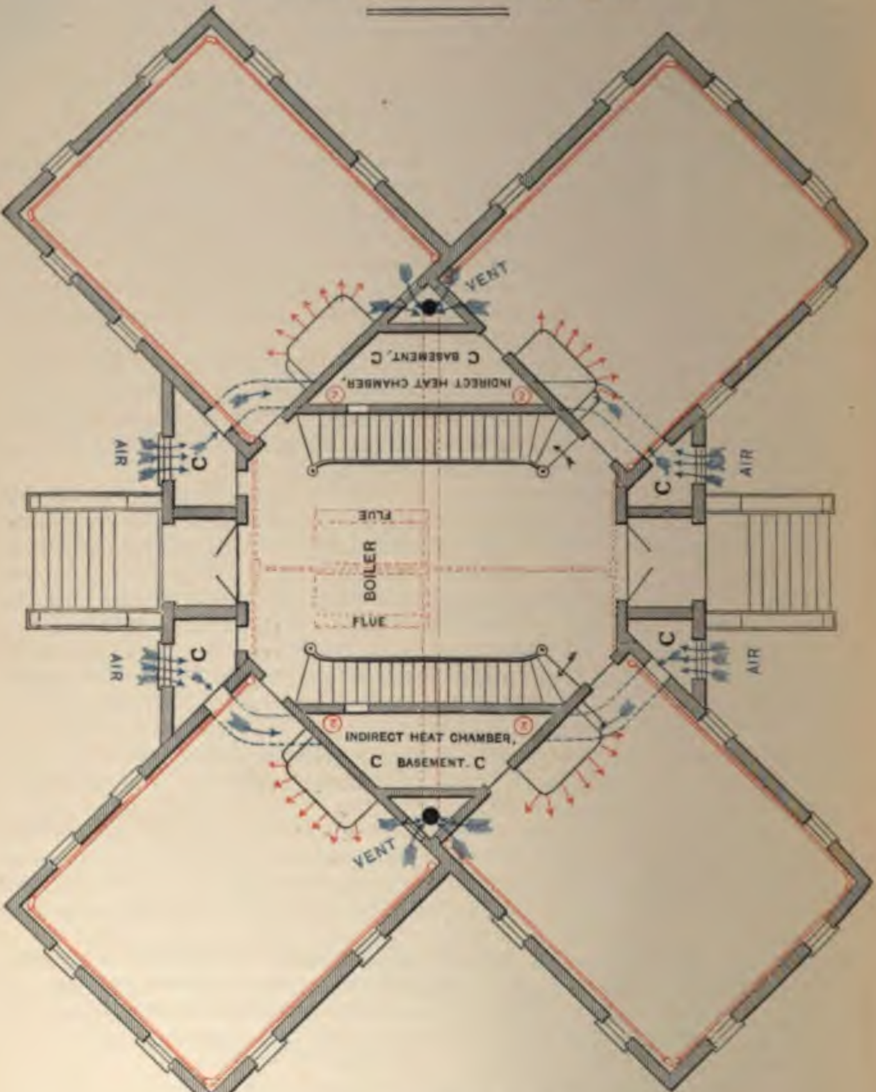
DIAGRAM No. 31.

NEW SCHOOLHOUSE DESIGN

Drawn and Designed by F. LANGDON, Architect, Winona, Minn.

ECONOMY OF CONSTRUCTION, LIGHT, HEAT, AND VENTILATION.

Double entrances, double stairways lighted.



WATER HEATING APPARATUS BY J. H. MILLS.

● are the iron smoke pipes inside the vent shafts.
(2) are the heat pipes for the second floor rooms.
Red arrows show boiler piping and pure warm air supply. **C**, closets first and second floors.
Blue arrows show air inlets to indirect chambers, and discharge into heated vent shafts.

CHAPTER XXVIII

METHODS OF SECURING VENTILATION.

THE MOVEMENT OF HEATED AIR IN FLUES OR CHIMNEYS.

THE different modes of producing ventilation may all be classed under two general heads — the natural and the mechanical. All the methods of spontaneous effusion, produced by the unequal density of two columns of air, whether caused by chimney draughts or otherwise, belong to the former class; while the various methods of ventilating by fans and blowers belong to the latter class.

Of these different modes the mechanical is the most effective; the natural, sometimes, but not always, the most economical. If a column of air contained in a tube or chimney be heated, it expands according to an ascertained law, applicable to all gaseous bodies; namely, that the expansion is equal to $\frac{1}{480}$ of its volume for each degree Fahr., that the temperature is raised from 32° to 212°. If this column of air be 10 feet high, and have its temperature raised 20°, then it will expand $\frac{20}{480}$, or $\frac{1}{24}$ of its bulk; so that its specific gravity would be diminished, and it would require a column of air 10 feet 5 inches high to balance a column of the external air 10 feet high, when the temperature of the latter is 20° lower than that of the former. But as the height of the heated column is limited by the height of the tube or chimney, which we may suppose to be only 10 feet high, the colder column presses it upwards with a force proportionate to this difference in weight, and with a velocity equal to that acquired by a body falling through a space equal to the difference in height that two columns of equal *weight* would occupy, which in this case is 5 inches.

Now, the law of gravitation is this: that the velocity of descent is relatively as the square root of the distance through which the body falls; and, as a body falls $16\frac{1}{12}$ feet in a second, the velocity will be, agreeable to the known law of gravitation, equal to 8 times the square root of the height of descent, in decimals of a foot; or $2\sqrt{gh}$ where g is the distance through which a falling body descends in one second of time, namely 16.09 feet, and h the height of the descent. (See also table 26, diagram 32, and table of the expansion of air by heat.)

The rate of efflux, however, is subject to certain corrections, on account of the contaminations which increase the specific gravity of the escaping air, and also in consequence of friction. In general practice a deduction of from one fourth to one third of the initial velocity is necessary to compensate for these several effects, and to represent the true rate of efflux. The velocity of discharge per second through ventilating tubes or chimneys, will, therefore, be found (after the difference in height of the two columns of air has been calculated in the manner already stated) to be equal to 8 *times the square root of the difference in height of the two columns of air in decimals of a foot;* this number reduced one fourth, to allow for friction, and the remainder multiplied by 60, will give the true velocity of efflux *per minute;* and the area of the tube in feet, or decimals of a foot, multiplied by this latter number, will give the number of cubic feet of air discharged per minute.

The following table, No. 26, shows the discharge *per minute* through a ventilator *one foot square* for various heights and differences of temperature, the allowance (as already stated) of one fourth for friction having here been made.*

In the upper part of the table is shown the discharge, per foot in height of the ventilator; this multiplied by the square foot of the height (table B), is the number of cubic feet per hour for a flue of one square foot section. Where the sectional area of the flue is less or greater, the amount of the discharge will be proportionately decreased or increased, the ratio being found by dividing the sectional area of the flue in square inches by 144.

As the temperature in the flue rises, the flow of air is largely increased. The table also illustrates the improved ventilation observed in cold weather when the temperatures outside the flue are low.

The power that causes the upward motion of the heated air is extremely small, being merely the difference in weight between air at different temperatures. It is apparent that the conditions may be easily altered by adverse influences. Thus, for example, the effect of pressure of the wind is frequently sufficient to reverse the current in chimneys; *where the temperatures in the flue are low, as in most cases of ventilating ducts, the dicharge is still more variable.*

Table No. 27 shows the sizes required in practice for warm-air flues and ducts from indirect radiator stacks heated by low-pressure steam or water.

The column to the left gives the number of square feet of heating surface in the stack. Following this is the contents of rooms in cubic feet supplied with heat, the proportions of heating surface to space warmed, ranging from forty to eighty cubic feet of space per square foot of radiator.

The sizes of flues required to supply different floors will be less in the upper stories, the power decreasing with the height of the heated column, as shown in the table above. The proportion for the same floor is taken as two inches of flue section per square foot of radiating surface, corrected to uniformly increase the sizes of the smaller flues.

The proper sizes of registers are shown in the adjoining columns, with allowance of one-third for obstruction of the register face by metal-work.

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* See also diagram No. 32, and table No. 30, page 543.

TABLE No. 26.

The Discharge of Air per minute through Ventilating Flue of One Square Foot Section, and One Foot High for different Temperatures of Air Outside the Flue as per formula.

C = Air discharged per minute in cu. ft.
H = Height of flue in ft.
t_1 = Temperature in flue, Fahr.
t = Temperature outside, Fahr.

$$C = \frac{3}{4} \times 480 \times \sqrt{\frac{H\,(t_1 - t)}{459 + t}}$$

A EXCESS OF TEMPERATURE OF AIR IN FLUE OVER OUTSIDE AIR.

Temperatures of Outside Air.		5°	10°	15°	20°	25°	30°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°	95°	100°
	0°	38	53	65	76	84	92	100	106	113	119	125	130	136	141	145	150	155	160	164	168
	12	37	53	63	75	83	91	98	105	111	118	124	128	134	139	144	148	153	158	162	166
	22	37	52	62	74	82	90	97	104	110	117	122	127	132	137	142	147	152	156	160	165
	32	36	51	62	73	81	89	96	103*	109	115	120	126	131	136	141	146	150	154	159	163
	42	36	51	62	72	80	88	95	102	108	114	119	125	130	135	140	144	148	153	157	161
	52	36	50	62	71	80	87	94	101	107	113	118	124	129	134	139	143	147	151	155	159
	62	35	50	61	71	79	86	93	100	106	112	117	123	127	133	137	141	146	149	154	157
	72	35	49	61	70	78	85	92	99	105	111	116	121	126	131	136	140	144	147	152	155
	82	35	49	60	69	77	85	91	98	104	110	115	120	125	130	134	138	143	146	151	154
	92	34	48	60	69	77	84	90	97	103	109	114	119	124	128	133	137	141	145	149	153
	102	34	48	59	68	76	83	90	96	102	108	113	118	123	127	131	136	140	144	148	152

B SQUARE ROOTS OF THE HEIGHTS OF FLUES, MULTIPLIERS FOR ABOVE TABLE.

Col. H = Height of flue in feet.	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$	H	$\sqrt{H}$
	1	1.	9	3.	17	4.12	25	5.	33	5.74	41	6.40	49	7.	57	7.55	65	8.06	73	8.54
	2	1.41	10	3.16*	18	4.24	26	5.10	34	5.83	42	6.48	50	7.07	58	7.62	66	8.12	74	8.60
	3	1.73	11	3.32	19	4.36	27	5.20	35	5.92	43	6.56	51	7.14	59	7.68	67	8.19	75	8.66
	4	2.	12	3.46	20	4.47	28	5.29	36	6.	44	6.63	52	7.21	60	7.75	68	8.25	76	8.72
	5	2.24	13	3.61	21	4.58	29	5.39	37	6.08	45	6.71	53	7.28	61	7.81	69	8.31	77	8.77
	6	2.45	14	3.74	22	4.69	30	5.48	38	6.16	46	6.78	54	7.35	62	7.87	70	8.37	78	8.83
	7	2.65	15	3.87	23	4.80	31	5.57	39	6.24	47	6.86	55	7.42	63	7.94	71	8.43	79	8.89
	8	2.83	16	4.	24	4.90	32	5.66	40	6.32	48	6.93	56	7.48	64	8.	72	8.49	80	8.94

Example: To find the discharge of air from a flue 10 feet high and one square foot section when the temperature of the outside air is 32° and that of the air in the flue is 72° Fahr.

The excess of temperature of the air in the flue over that outside is 72° − 32° = 40°, and the discharge from flue one foot high for this excess of temperature of 40° is, by the upper table, 103* cubic feet per minute. This multiplied by the square root of the height of the flue (or $\sqrt{10} = 3.16$*, table B) = 325 cubic feet discharged per minute.

TABLE No. 27.

Warm Air Flues in Square Inches and Registers for Stated Amounts of Indirect Radiating Surface.

Sq. Feet of Radiator Surface.	Heating Surface to Space Warmed.					1st Floor.		2d Floor.		3d Floor.	
	1:40	1:50	1:60	1:70	1:80	Size HotAir Flue.	Size of Register.	Size HotAir Flue.	Size of Register.	Size HotAir Flue.	Size of Register.
	Contents of Rooms in Cubic Feet.										
20	800	1,000	1,200	1,400	1,600	60"	8×12"	50"	8×10"	40"	6×10"
30	1,200	1,500	1,800	2,100	2,400	79	8×15	64	8×12	49	8×10
40	1,600	2,000	2,400	2,800	3,200	98	10×16	78	8×15	58	8×12
50	2,000	2,500	3,000	3,500	4,000	117	12×15	92	10×14	67	9×12
60	2,400	3,000	3,600	4,200	4,800	136	12×19	106	10×16	76	8×15
70	2,800	3,500	4,200	4,900	5,600	155	12×19	120	12×15	85	9×14
80	3,200	4,000	4,800	5,600	6,400	174	12×19	134	12×15	94	10×14
90	3,600	4,500	5,400	6,300	7,200	193	14×22	148	12×19	103	10×16
100	4,000	5,000	6,000	7,000	8,000	212	14×22	162	12×19	112	12×15
110	4,400	5,500	6,600	7,700	8,800	231	15×25	176	14×22	121	12×15
120	4,800	6,000	7,200	8,400	9,600	250	15×25	190	14×22	130	12×15
130	5,200	6,500	7,800	9,100	10,400	269	20×20	204	14×22	139	12×19
140	5,600	7,000	8,400	9,800	11,200	288	20×20	218	14×22	148	12×19
150	6,000	7,500	9,000	10,500	12,000	307	20×24	232	15×25	157	12×19
160	6,400	8,000	9,600	11,200	12,800	326	20×24	246	15×25	166	12×19
170	6,800	8,500	10,200	11,900	13,600	345	20×26	260	16×24	175	14×22
180	7,200	9,000	10,800	12,600	14,400	364	20×26	274	20×20	184	14×22
190	7,600	9,500	11,400	13,300	15,200	383	21×29	288	20×20	193	14×22
200	8,000	10,000	12,000	14,000	16,000	402	21×29	302	20×24	202	14×22

The method of spontaneous or gravity movement of air in flues, which has been described, requires in every case that the air of the room to be ventilated (and thus the flue) shall be of a higher temperature than the external air. *Where this is not the case, no motion will ensue that is of any practical use in ventilation.*

The differences of temperature that may exist in chimneys or ventilating shafts, where no extraneous heat is applied, cause a certain but limited motion of the lighter air, *corresponding* (*as we have seen in the table*) *to the difference of temperature and height of the shaft.*

In the following diagram, No. 32, we may trace at a glance some of the principal results that are found by the use of the tables. For instance, the curved lines show flues from 1 to 114 feet high, with internal temperatures of from 62° to 462°; while at the side are set the degrees Fahr., representing the temperatures of the air. Following the black lines of the table (left to right) until they intersect the red lines, we have the velocity of the air in any flue of the height and temperature noted. As far as ventilation is concerned, we may confine our observation to the lower four spaces, and to the region bounded by the letters A, B, C, D, since 137° is as high a temperature as it is economical to employ for removing air by means of heat in the flue.

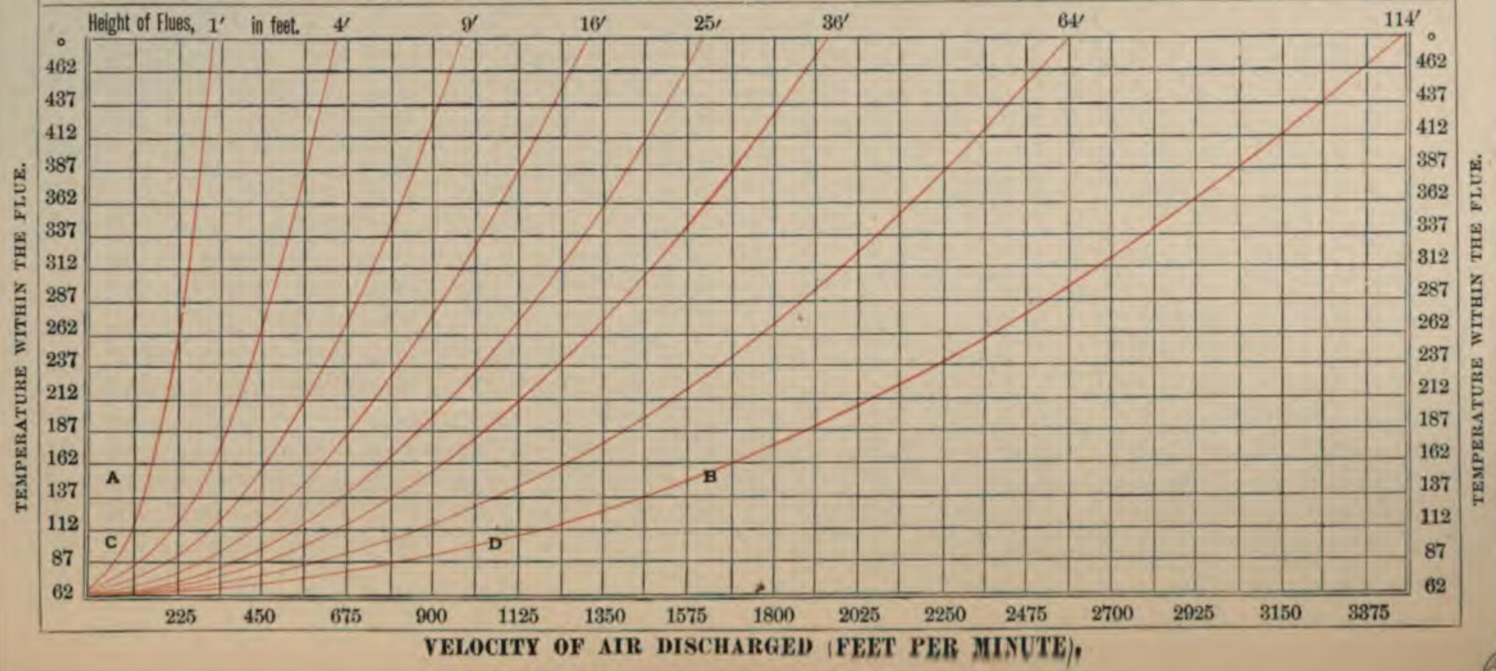
Noting carefully now where the red line (representing the height of any flue) crosses a straight line from A to B or from C to D, we shall see that for small differences of temperature and low flues that the discharge is comparatively small; thus, outside air 60°, temperature in the flue 87°, difference 27°, the height of the flue being 36 feet, and area 1 square foot, the discharge is 450 cubic feet of air in 1 minute, or 450 x 60 = 27,000 cubic feet in 1 hour's time. Again, outside air and height and area of the flue the same, temperature in the flue 137° (difference 77°), the discharge is 787 cubic feet per minute, or 787 x 60 = 47,220 cubic feet per hour; by quadrupling the heat or the difference in temperature we substantially double the discharge; this without reference to the area of the flue. In table No. 39 (Chapter XXX.) may be found a summary of all the co-relating conditions in the movement of air by heat and by mechanical methods. Experiments 9, 10, and 11 are of particular interest to steam heating engineers, and all who contemplate increasing the movement of air in flues by the use of steam coils. Much as may be said in favor of natural ventilation, and evident as it is that all successful ventilation must depend on a studious and skillful conformity to the few natural laws underlying the whole process, it will still remain questionable, after everything possible has been done to produce draught by differences of height and temperature, whether it is possible to supply at all times a large amount of air of the necessary quantity and quality.

DIAGRAM No. 32.

CUBIC FEET OF AIR DISCHARGED BY HOT AIR AND VENTILATING FLUES, FOR DIFFERENT HEIGHTS AND TEMPERATURES.

Being the Theoretical Discharge per Square Foot of Flue Section (Outside Air at 60°).

Reduced One Fourth to allow for Friction of Registers and Flues. (See Tables Nos. 26 and 27).



THE CAPACITY OF AIR FOR HEAT AND FUEL REPRESENTED.

We shall see that in table No. 39 may be found examples of about all the different methods of producing a movement of air for ventilation, or indeed any other purpose, also the cost of such movement. ***This, of course, does not take into account the original or total amount of heat contained in the air, or the cost of heating it from the temperature without to that within the building,*** this being another and separate issue.

There are many other uses for heated air besides that of warming buildings, such as drying fabrics, timber, bricks, etc., and it seems desirable to know without elaborate calculation just what heat is contained or carried in the air at any temperature, as well as in changing the air for ventilation.

It is, however, in connection with ventilation and the discharge of air that this table becomes interesting and instructive, since by it we may see what it costs to quicken the discharge of air by raising its temperature in the exit flues.

There has been much misconception and sometimes misstatement of the amount of heat required to cause certain velocities in ventilating flues. This matter has been treated so fully that little more can be added to it except to note the following conditions from table No. 39, page 583:—

Taking the first eleven experiments (average) we read: Area of flue, 12 square feet; height, 51 feet; outside air, 51°; air in the flue, 131°; difference of temperature, 80°.

Thus, each 5,000 cubic feet of air discharged carries with it 7,688 units of heat, which divided by 7,000 = 1.9 pounds of coal.

If the surfaces to heat 5,000 cubic feet of air per hour were steam pipe, we see (experiments 9, 10, and 11) that it would require 5,000 ÷ 388=12.9 square feet, and that this heating surface must be placed at the *bottom of the shaft, the air being brought in immediately below the pipe, or any other heating surface so employed.*

Table No. 28 has been prepared to show this loss, and may be consulted both as to the heat contained in the air, the pounds of coal represented, and thus the cost, knowing the value of the fuel at any locality. It also shows the boiler and heating surface in pipe or radiators (gravity circulation) to furnish the stated amount of heat.

* Thus (example) 100,000 cubic feet of air raised 100° = 1,922 x 100 = 192,200 (units) ÷ 7,000 = 27 pounds of coal; this requires (lower line) 192,200 ÷ 400 = 480 square feet of pipe surface to do the work, and 192,200 ÷ 3,000 = 64 square feet of boiler with 3 square feet of grate, or one third of this for furnace plate = 21 feet.

---

* See the same stars (*) set in the table and lower line for the radiator and boiler surface.

TABLE No. 28.

Heat Required to Raise the Temperature of Air from 1° to 140°.

POUNDS OF COAL REQUIRED FOR THIS EFFECT, PROVIDING FOR LOSSES IN TRANSMISSION, 7,000 HEAT UNITS PER LB. COAL CONSUMED.

Example: 1,000 cub. ft. of Air raised 1° requires 19.22 Units of Heat.
*100,000 cub. ft. Air raised 100° requires ‡1922 × 100 = †192,200 ÷ 7,000 = 27 lbs. Coal.

Cubic Feet.	1°	5°	10°	20°	30°	40°	50°	Degrees Raised. 60°	70°	80°	90°	100°	110°	120°	130°	140°
1,000	‡19.22	96.1	192 2	384.4	576.6	768.8	961.	1153.2	1345.4	1537.6	1729.8	1922.	2114.2	2306.4	2498 6	2690.8
5,000	96.10	480.5	961.	1922.	2883.	3844.	4805.	5766.	6727	7688.	8649.	9610.	10571.	11532.	12493.	13454.
10,000	192.2	961.	1922.	3844.	5766.	7688.	9610.	11532.	13454.	15376.	17298.	19220.	21142.	23064.	24986.	26908.
20,000	384.4	1922.	3844.	7688.	11532.	15376.	19220.	23064.	26908.	30752.	34596.	38440.	42284.	46128.	49972.	53816.
30,000	576.6	2883.	5766.	15320.	17298.	23064.	28830.	34596.	40362.	46122.	51894.	57660.	63426.	69192.	74958.	80724.
40,000	768.8	3844.	7688.	15376.	23064.	30752.	38440.	46128.	53816.	61504.	69192.	76880.	84560.	92256.	99949.	107632.
50,000	961.0	4805.	9610	19220.	28830.	38440.	48050.	57660	67270.	76880.	86490.	96100.	105702.	115320.	124930.	134540.
60,000	1153.2	5766.	11532.	23064.	34596.	36128.	57660.	69192.	80724.	92256.	103788.	115320.	128844.	138384.	149916.	161448.
70,000	1345.4	6727.	13454.	26908.	40362.	53816.	67270.	80724.	94178.	107632.	121086.	134540.	147986.	161448.	174902.	188356
80,000	1537.6	7688.	15376.	30752.	46128	61504.	76880.	102256.	107632.	123008.	138384.	153760.	169128.	184512.	199888.	215264.
90,000	1729.8	8649	17298.	34596.	51894.	69192.	86490.	113788.	121086.	138384.	155682.	172980.	190270.	207576.	224874.	242172.
*100,000	1922.0	9610.	19220.	38440.	57660.	76880.	96100.	125320.	134540.	153760.	172980.	†192200.	211412.	230640.	249860.	269080.
200,000	3844.	19220.	38440	76880.	115320.	153760.	192200.	250640.	269080.	307520.	345960.	384400.	422824.	461280.	499720.	538160.
300,000	5766.	28830.	57660.	115320	172980.	230640.	288300.	375960.	403620.	461280.	518940.	576600.	634236.	691920.	749580.	807240.
400,000	7688.	38440.	76880.	153760.	230640.	307520.	384400.	501280.	538160.	615040.	691920.	768800.	845648.	922560.	999940.	1076320.
500,000	9610.	48050.	96100.	192200	288300.	384400.	480500.	626600.	672700.	768800.	864900.	961000.	1057060.	1153200.	1249300.	1345400.
	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	Units of Heat.		. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .

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* NOTE. — To find the radiator surface (gravity conditions), ÷ the units of heat by 400; for boiler surface, by 3,000.

* "In all our attempts to ventilate houses and at the same time preserve a uniform temperature throughout, we must bear in mind that we are living at the bottom of a sea of air, which presses equally every way, and whose weight and pressure and their laws are accurately known. Any portion of air on being heated expands in volume, and becomes specifically lighter than the neighboring portions, which have therefore a greater tendency to fall toward the earth, and thus push the lighter portion upward. Heated air has thus a tendency to ascend, not, however, from any such power in itself, but solely because it is pushed upward by the fall of the colder, denser, and therefore heavier air taking its place; just as the lighter scale of the balance ascends because it is pushed up by the heavier scale, and not because of any power of its own to ascend. These simple truths are frequently overlooked by amateur contrivers of ventilating schemes; they know the fact that hot air rises, and they think, therefore, that nothing more is necessary than to make an aperture at the top of the room, and through it the foul, heated air will naturally go out! But it will not do so unless an exactly equivalent volume of colder air find entrance at the same time to push it out. In an air-tight chamber with a single aperture at the top, a lighted candle will go out, even though the aperture is quite large enough to supply an ample change of air. Where a candle will go out, a human being will die.

"The power necessary to effect ventilation may be derived from the expansion of the air by heat specially applied for that purpose in the outlet flue or chimney, or from fans or blowers driven by machinery, or from jets of steam or a falling stream of water. It is also theoretically possible to produce the required movement of air by cold as well as by heat; all that is essential being that there shall be a difference in temperature between the space to be ventilated and the outer air, and sufficient channels of communication between the two.

(See table No. 39, page 583.)

"Ventilation by means of heat will usually be effected by what is commonly called an aspirating or ventilating chimney, which is a shaft or flue so constructed that the air in it can be heated without necessarily heating the room or rooms from which it is desired to withdraw the air, so that no discomfort need be caused by its use in warm weather.

"This heat may be applied by means of an open grate placed in the shaft, as is done in the aspirating tower for the House of Commons, and in mines, or by means of a stove, heating a sheet-metal pipe passing up the chimney, or by gas jets, or by hot-water boilers, or by the circulation of hot water or steam in coils of pipe or radiators suitably arranged in the chimney."

* Dr. J. S. Billings.

TABLE No. 29 AND DIAGRAM No. 33.

THE EXPANSION OF DRY AND MOIST AIR.

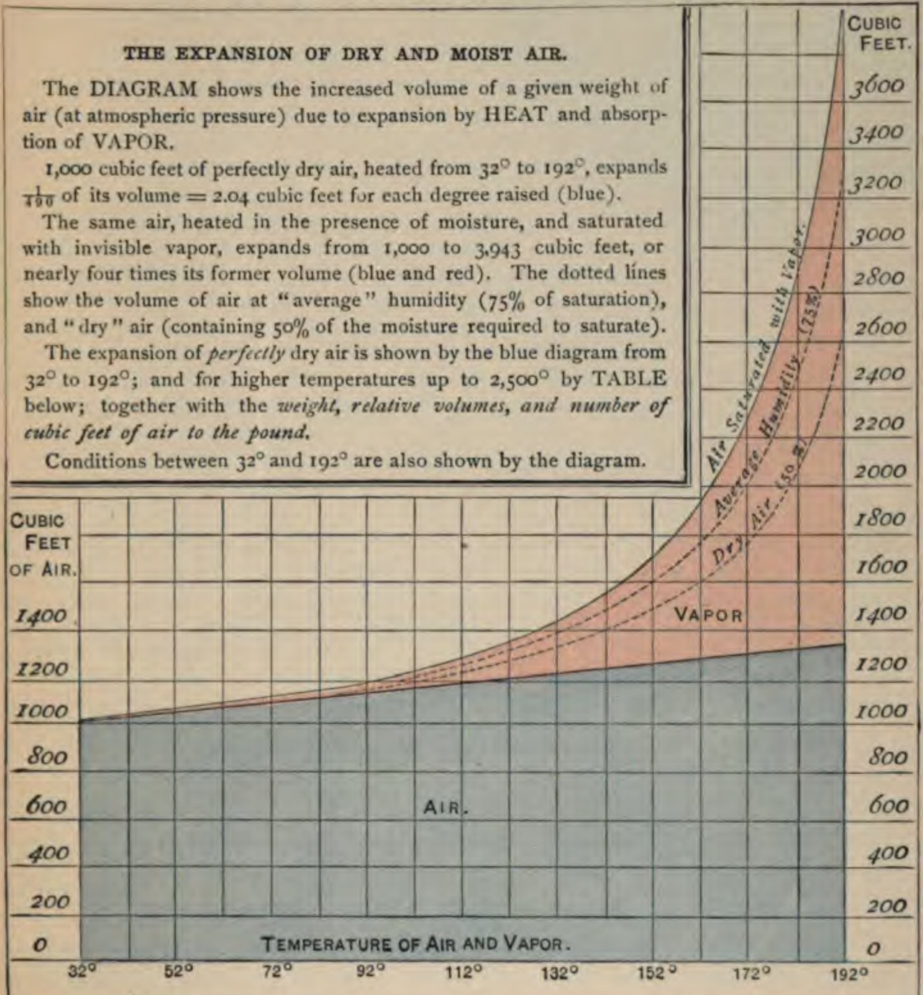
The DIAGRAM shows the increased volume of a given weight of air (at atmospheric pressure) due to expansion by HEAT and absorption of VAPOR.

1,000 cubic feet of perfectly dry air, heated from 32° to 192°, expands $\frac{1}{490}$ of its volume = 2.04 cubic feet for each degree raised (blue).

The same air, heated in the presence of moisture, and saturated with invisible vapor, expands from 1,000 to 3,943 cubic feet, or nearly four times its former volume (blue and red). The dotted lines show the volume of air at "average" humidity (75% of saturation), and "dry" air (containing 50% of the moisture required to saturate).

The expansion of *perfectly* dry air is shown by the blue diagram from 32° to 192°; and for higher temperatures up to 2,500° by TABLE below; together with the *weight, relative volumes, and number of cubic feet of air to the pound.*

Conditions between 32° and 192° are also shown by the diagram.



Temperature.	Relative Volume.	Wt. of 1 Cubic Ft. Lbs.	Cubic Feet per lb.
0°	.935	.0864	11.59
12	.960	.0842	11.90
22	.980	.0824	12.15
32	1.000	.0807	12.40
42	1.020	.0791	12.65
52	1.041	.0776	12.91
62	1.061	.0761	13.16
72	1.082	.0747	13.41
82	1.102	.0733	13.66
92	1.122	.0720	13.92
102	1.143	.0707	14.17
112	1.163	.0694	14.42
122	1.184	.0682	14.67
132	1.204	.0671	14.92
142	1.224	.0660	15.18
152	1.245	.0649	15.43
162	1.265	.0638	15.68
172	1.285	.0628	15.93
182	1.306	.0618	16.18

Temperature.	Relative Volume.	Wt. of 1 Cubic Ft. Lbs.	Cubic Feet per lb.
192°	1.326	.0609	16.44
202	1.347	.0600	16.69
212	1.367	.0591	16.94
230	1.404	.0575	17.40
250	1.444	.0559	17.89
275	1.495	.0540	18.52
300	1.546	.0522	19.15
325	1.597	.0506	19.78
350	1.648	.0490	20.41
375	1.689	.0475	21.04
400	1.750	.0461	21.68
450	1.852	.0436	22.94
500	1.954	.0413	24.21
550	2.056	.0392	25.47
600	2.158	.0374	26.73
650	2.260	.0357	28.00
700	2.362	.0342	29.26
750	2.464	.0328	30.53
800	2.566	.0315	31.79

Temperature.	Relative Volume.	Wt. of 1 Cubic Ft. Lbs.	Cubic Feet per lb.
850°	2.668	.0303	33.06
900	2.770	.0292	34.32
950	2.872	.0281	35.59
1000	2.974	.0271	36.85
1100	3.177	.0254	39.38
1200	3.381	.0239	41.90
1300	3.585	.0225	44.43
1400	3.789	.0213	46.95
1500	3.993	.0202	49.48
1600	4.197	.0192	52.01
1700	4.401	.0183	54.53
1800	4.605	.0175	57.06
1900	4.809	.0168	59.59
2 00	5.012	.0161	62.11
2100	5.216	.0155	64.63
2200	5.420	.0149	67.16
2300	5.624	.0143	69.69
2400	5.828	.0138	72.22
2500	6.032	.0133	74.75

See tables Nos. 26 and 27 and diagram No. 32.

CHIMNEYS AS VENTILATING FLUES.

As chimneys are an important feature in all heating operations and where any form of solid fuel is to be burned, a few words about them will not be out of place, especially as many persons, including architects and builders, omit to give due consideration to the subject or the advice of practical heating engineers, who are often crippled for the want of a chimney flue of proper area and height for the work.

These remarks also apply to flues in which it is proposed to discharge air for purposes of ventilation, since the same rules apply equally to both, the power being the same; viz. heat.

It is, however, more difficult to obtain a good ventilating flue because the heat available is less, and the cooling influences greater.

Temperature inside the flue, then, being the only power to create draught and velocity, all means of increasing these should be availed of, and all means of preventing loss taken.

Thus a chimney flue in an outside wall is at disadvantage, due to the cold nature of the outside and• other surrounding walls, and will not yield more than two thirds of its possible duty; while, if a flue so situated is intended to convey away air at a low temperature, it is often a failure, due to the greater power of the cold air blowing down upon the top of the flue, often reversing the discharge.

If chimneys or other vent flues *must* be located in outside walls, the only remedy is to build them double, or with surrounding air spaces to prevent chilling effects.

The best and simplest way to secure good flues for either purpose is to make the lining of *vitrified tile* the size required, and the brick wall around this not nearer to the pipe than the flanges of the tile used. This will leave an air space of one and a half or two inches.

The tile furnishes a smooth glazed surface that will not crack, peal off, or foul up, and that can be had at a small first cost; in fact, at less cost than any flue lining could be built up of brick and mortar.

There are also other tile linings of square or oblong shape that make admirable lining or flues for the conduction of heat, as they may be used between the wooden partitions or in the place of a four-inch brick wall, their thickness being only about an inch. We will insert cuts if they arrive in time. As the matter of the movement of air for ventilation will be treated under that head, we will only refer to the area of the chimney flue and the imperative necessity that a good one should be provided by the architect, owner, or builder. Although there is some general information to be had, a simple rule is to allow for a heating apparatus, *sixteen square inches for each square foot of grate, and for power purposes twenty inches, or an increase of 25 per cent. with all the height available in either case.* See also pages 484, 485.

That the matter of chimneys is but imperfectly understood, may be proved by a glance at the roofs of buildings in almost any locality.

What is the meaning of all the heterogeneous collection of chimney caps, cowls, and patent clap-traps that disfigure the roofs of some of our best buildings—some high, some low, some leaning, some straight, some fixed, some movable or intended to move when there is wind enough to drive them around?

It means to the practical eye that the architect and his master mason missed their objective point, and that the hideous chimney pots are a record of their ignominious failure. A crying shame that, in addition to all the trouble incurred in trying to get good work from a poor tool, the fair outlines of the roof must permanently be disfigured by the motley collections of a race of chimney doctors, who have been called in by the owner to palliate a disease inherited and inherent in the plans for the buildings, or rather the plans of the chimneys.

I do not mean here or, indeed, anywhere to bear unduly upon the architect or suggest that he is indifferent to the success of this important detail of his construction,—nay, I am confident that there is no more interested party, and that he will be the first to see and appreciate practical suggestions in this direction. In fact, the better posted the architect is in the general difficulties of obtaining good draught for chimneys and ventilating exits, the more readily he will seek the advice of the heating and ventilating engineer.

It is not intended to assert that all wisdom and experience reside even in these specialists, since I have seen some terrible mistakes made under the direction and sanction of so-called practical men; and nothing is more common than to see them accept too little, or rush to the other extreme and insist on too much, flue. The engineer and heating contractor has much to learn in his difficult branch of mechanical science.

THE MOVEMENT OF AIR FOR VENTILATION.

I think it possible to have too large a chimney flue, as well as too small. If a chimney flue is too large, and the air be restricted below, double currents will be established in the flues. A cold current will drop down one side of the flue, and a warm current will pass up the other. In this case the heater and boiler is cut off from its best work, and only acts as a feeder to the warm current, in this case obeying the same law that water would under the like condition. Indeed, the two fluids obey the same laws of gravity in circulation.

The same adverse results also obtain when a disproportioned chimney is employed as a ventilating flue.

See article on chimneys, Chapter XXV.

As one of the best methods of abstracting air from a room is the open fireplace, we must not omit to give it credit, and in this connection to note that it is the fire on the grate, with the temperature thus communicated to the air, that causes it to rise, other air taking its place.

Open fireplaces, whether the fuel consumed in them is wood or coal, are among the very best natural ventilators that we have, and yet the question of expense is bringing them more and more into disuse. But there is no need to be discouraged on that score, because the eyes of all practical people are being opened to the importance of combining the twin forces of heat and ventilation in such a manner as shall tend, in the future, to prolong life, as well as render it more enjoyable.

When used in connection with other methods of heating, they become a useful auxiliary. The heat is imparted from them by radiation, which does not heat the air at all, except by first heating the walls and surfaces with which the air comes in contact; thus a degree of comfort is obtained without overheating the air. The sun heats the atmosphere in a similar way — by first heating the surface of the earth, which imparts heat to the air by contact.

The open fire is a valuable help in removing vitiated air from a room, and is therefore particularly useful in hospitals and other sick rooms. In a room that is occupied by women and children, and by men of sedentary occupation, and is heated by steam, hot water, furnaces, or stoves, a higher degree of temperature is required for comfort than when a small fire is used in connection with other means.

There is, however, a caution that should be given in connection with the open fire, and that is the liability of cold draughts over any person sitting *between the fire and a window, door, or other source of cold-air supply to the fire.*

* Memorandum of movements of air in vent shaft at School No. 10, May 16, 1885 — shaft in the centre of the house, height 54 ft.; area, 4 x 4 ft., 16 sq. ft. opening; opening in base, 24 x 30 inches, or 5 sq. ft.

Outside temperature, 64°; attic floor, 62°; second floor, 58°; first floor, 50°; average for whole shaft, 56°. Difference between the temperature of air in the shaft and that outside was thus 8°. Movement of air in shaft *downwards*, 205 ft. per minute.

The discharge of air as computed by table No. 24, for a shaft 54 ft. high and a difference of temperature of 8°, with outside air 62°, 45 x 7.35 = 321 ft. per minute. This is for entirely free movement of the air into and out of the flue.

In the above example the air, after passing down the flue, was discharged into a closed basement through an opening only one third the total area of the chimney.

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* Buffalo, N. Y., April 1885.

* One of the many fallacies and errors which have from time to time been urged by writers on ventilation, and with which it is desirable that the architect and sanitary engineer should be familiar, — since they are constantly coming up afresh in the form of a letter or patent or of a letter of advice to the daily press, — is that of the effect of syphons or syphon-like arrangements as exit flues for foul air, and the effects of Archimedian screw ventilators.

"This matter of terminals of foul air and smoke flues occupies such a prominent, although for the most part wholly unmerited, place in the literature of ventilation, and so much stress is laid on the merits of this or that particular form of cap or cowl, not only by patentees, but by some architects, that a few more words on the subject seem necessary."

"In 1878 a series of experiments were made at the Royal Observatory, Kew, England, upon ventilating exhaust cowls, by a committee composed of W. Eassie, Rogers Field, and Douglas Galton, whose names are a sufficient warrant for the care with which the tests were made. The results are given in the following report, which is a model of brevity and clearness: —

"'The sub-committee appointed at Leamington to test the ventilating exhaust cowls, beg to report that they have given the matter their most careful attention, and carried out at the Royal Observatory, Kew, an elaborate series of about one hundred experiments, on seven different days, at different times of the day, and under different conditions of wind and temperature.

"'After comparing the cowls very carefully with each other, and all of them with a plain open pipe, as the simplest and, in fact, only available standard, the sub-committee find that none of the exhaust cowls cause a more rapid current of air than prevails in an open pipe under similar conditions, but without any cowl fitted on it. The only use of the cowls, therefore, appears to be to exclude rain from the ventilating pipes; and, as this can be done equally, if not more efficiently, in other and similar ways without diminishing the rapidity of the current in the open pipe, the sub-committee are unable to recommend the grant of the medal of the Sanitary Institute of Great Britain to any of the exhaust cowls submitted to them for trial.'"

"With regard to the various forms of Archimedian screw ventilators, as usually made, they have no effect, unless driven by power independent of the wind. *In calm weather, of course, all forms of cowls are entirely inoperative, except as furnishing more or less obstruction to the free egress of air;* and on a still, warm day, when the temperature within a large building may be several degrees lower than that out of doors, there will be a tendency to a reversal of the current and to down draughts through any form of cowl that can be devised.

"It often seems to be supposed by those advocating the use of this or that particular cowl, that the cowl itself has some mysterious effect in producing currents of air within it independent of wind or of differences of temperature, and that, therefore, if enough cowls are provided, we can make sure of the effect desired under all circumstances. This is, of course, not the case, nor does it by any means follow that the use of two or more cowls on a building will produce more effect than one; in fact, the effect may be just the reverse.

"For example, I have seen a large three-story building in which the foul-air flues from the several floors terminated in the open space of the attic, and then half a dozen patent cowl ventilators were placed in the roof to complete the arrangement.

"The result was that the several cowls pulled against each other, and, as they were only nine inches in diameter, the result was sometimes almost inappreciable. Had a single shaft, three feet in diameter and properly capped, been insert
results would have been obtained, though this plan of using
foul-air reservoir is one that should be condemned under all c

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* Dr. J. S. Billings' "Heating and Ventilati

That nearly all failures to secure a proper air supply or change in inhabited rooms are the result of deficient knowledge of air and its controlling forces, is but a truism, and one easy to understand.

It is clear, however, that it is more the question of expense rather than of ability how to reach that result, that hampers and finally obscures most efforts at change of air in the dwelling and in public buildings.

Although efficient ventilation will not cost a very large sum per room, it cannot be denied that "somewhat" will be added to the first cost of the dwelling, and that this "somewhat" the speculative builder will not add until he finds intending tenants or purchasers refuse to take houses that have no proper or modern means of ventilation and warming.

As with houses, so with other buildings — they are frequently undertaken with a limited original appropriation, which those in charge of the construction find it hard to increase, even to secure sanitary warming and ventilating arrangements.

In this matter the architect is doubtless more to blame than any one else, in not making ventilation a *first* instead of a *last* consideration, and in putting such cost (less at that time than at any other) into his original estimate. That some of the building profession have given the subject of ventilation attention, is true, and that many make attempts at constructing flues in the walls, both to bring warm air into the rooms and to take away the air that has been vitiated by the various sources of contamination.

Since, however, architects, builders, and committees are beginning to learn that their success in any *indirect* system of heating, as with furnaces or steam radiators located in remote chambers, is really dependent on how much air can be taken through the room, more attention is paid to those flues that are to carry the air away, and which, as has been said, are the key to the efficiency of any system of ventilation.

Even when force or power is applied to cause motion of the air, some regular and liberal supply of exit flues is required on which the fan may act, either by the plenum or exhaust methods.

In short, no building or room can be made to breathe, unless proper tubes and lungs are first provided; and, unless a building be made to breathe, it is a dead creation and a source of death to those who inhabit it. It is in the flues, however, that reasons of failure are oftenest found and may be expected; for, unless of a proper size and rightly located, these exit flues will, as they generally do, prove complete failures. The reason of this will be more fully considered later. For the present it may be sufficient to say, that exit flues located in a cold or outside wall may bring some cold air into a room; but, to carry warm air out, they are generally ineffective. For size of air flues, see pages 543, 544.

In its great and leading features ventilation presents no complexity as applied to individual apartments, though a deficiency of knowledge in those who conduct or manage it often renders the most simple and valuable plans of no use. But in complicated structures where many contending circumstances require adjusting, and where very limited measures have been introduced, it is often difficult to say whether lack of skill in the management of means at command, or unreasonable anticipations as to the effects attained when the apartments are overcrowded, may be most at fault.

It has been supposed by many persons, architects and others, when considering the matter of ventilation, that the most which was needful was to provide some kind of chimneys or vent flues in the walls for carrying away the vitiated air. They give little or no thought as to area, size, or condition of the flue, where it leaves the room or building, and often these flues do not pass out of the roof at all, but open into the space in the attic, from which there is no practical discharge outlet; and, if there were, this air — what little would find its way into the cold chamber — would become chilled, and have no power to continue its journey out of any secondary discharge pipe not directly connected with the vent flues themselves.

But supposing that some rational vent flues have been built in the walls, and that there is a considerable difference between the air of the room and the air in the vent flue, *but little air will be removed unless an equal amount of air warmed to the same temperature is supplied. In other words, the air cannot flow up and out of any room faster than it is supplied. It is therefore the supply of air that makes removal of any considerable part of it possible.* If persons when thinking of air would compare it to water, which, being also a fluid, flows in obedience to the same laws, there would be less confusion on the subject of ventilation.

In a water apparatus for heating a building, the water in the boiler and pipes moves and circulates through them by the addition or abstraction of heat, and this is the motive power that must be applied to secure the movement of air in what may be termed natural or gravity methods of ventilation.

No one expects water to move in any direction without power being applied in some form; and we therefore secure it either by difference of level due to position, or of pressure produced by an engine or pump. *With air, difference of temperature means motion, just as differences of level, and we have velocity in proportion to these differences, and volume in proportion to the height and area of the discharge shaft.* Increasing the height of the flue (the temperature of the air remai[illegible]n), the velocity of the discharge is *increased;* th[illegible]tional to the *square root* of the height of the h[illegible]

AN EXAMPLE OF A VENTILATED DWELLING.

*This house consists of a central lobby 24 x 9 feet, with rooms 19 feet deep on each side, and having ground, house, bedroom, and attic floors. The total cubic area of the house is about 38,000 cubic feet. The primary inlet is 5⅛ square feet; the secondary inlet, about 16 square feet; the inlets to the rooms, as large as they could be made; the total area of the outlets from the rooms of the house proper (and all the others were closed during the experiments) into the foul-air chamber is about 3⅛ square feet; the downcast shaft (or outlet from the foul-air chamber) is about 5¼ square feet, and the upcast (or ultimate vitiated-air outlet), at the place where the anemometer was, is 3¾ square feet; height of vitiated-air chamber above heating chamber, 47 feet; length of downcast shaft, 35 feet, and length of upcast, 55 feet; the canvas stretched across the primary inlet is 171 square feet; the primary inlet is provided with valves; the secondary inlet is protected with hot-water pipes, which also extend into the central lobbies, giving a length of 285 feet; the chimney throats are provided with valves and register grates, and the outlets from the rooms are provided with valves between the room and the foul-air chamber; nearly all the windows of the house are fixed like church windows; there is a small window in the end of the foul-air chamber, and a small, well-made, tightly fitting glass door.

The results arrived at are the following; viz., that in the house, with an open kitchen fire (the opening 4 feet from side to side and 2 feet high above the top bar), the grate 17 inches from side to side, 11 inches from back to back, and 14 inches from bottom of grate; the smoke flue beginning 4 feet 6 inches above the top bar, i. e. 5 feet above the centre of the fire, smoke flue 54 feet long, made of glazed earthen-ware pipes 1 inch thick, the internal diameter 15 inches, and the chimney pot 13 inches; with a good kitchen fire burning and the water boiling.

With these conditions the smoke from the kitchen fire has a temperature of 230° as it enters the smoke flue, and 195° as it escapes at the chimney top; and, with the upcast surrounding the whole length of the smoke flue 46 feet, and flue pretty clear of soot, we thus, therefore, abstract only 35° of the waste heat of the smoke from the kitchen fire, and that though the upcast goes up close behind the boiler; and, therefore, we gain only an average increase of temperature of about 20° between the outside air and the air in the upcast for the production of draught or the suction of vitiated air out of the house; and we thus produce a velocity of about 220 feet per minute in the upcast.

How much more of the heat we should gain by having a cast-iron smoke flue, close kitchen range, and contracted fire pot, we cannot at present say; but it is very likely we should gain at least 50° to 70°, which would possibly increase the velocity to about 300 or 350 feet per minute in the upcast.

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*"Health and Comfort in House Building," J. Drysdale and J. W. Hayward, London.

METHODS OF ARRANGING VENTILATING FLUES.

In buildings of such size and importance that it is worth while to provide some form of centralized heating for them by means of steam or hot water, the architect will usually prefer to gather the majority of the foul-air flues into one large upcast shaft, in connection with which he can provide means to secure a constant current, and to regulate its velocity to suit the varying requirements of the season or of the inmates of the building. This collection of flues into a central shaft may be effected in four different ways.

The *first* of these is what *Planat* calls *aspiration from above*, by which he does not mean aspiration from the upper part of each room, but from a point above all the rooms, — usually in the attic, — to which point all the foul-air flues are made to converge and enter a single shaft, in connection with which is a furnace or coil of steam pipe to give additional heat and ascensional force to the air.

The *second* method is to carry the foul-air flues of each story horizontally to the central shaft, which they enter at the level of the ceiling, which may be termed *aspiration on a level*, or horizontally.

The *third* method is to carry all the foul-air flues downward to the cellar, where they are collected into a duct, or ducts, leading to the central upcast shaft. This is *aspiration from below*, and may be seen to advantage in the Smead-Ruttan system.

The *fourth* system is a combination of the *first* and *third*, the rooms in the upper story having their flues pass upward, while the remaining floors are ventilated by flues passing downward. *This may stand for the Fuller & Warren, or mixed system.*

As the aspirating power of the shaft depends on the height of the heated column of air, as well as on the difference between the temperature in the shaft and that of the external air, it is evident that, the nearer the bottom of the shaft the extra heat is applied, the greater will be its efficacy, bearing in mind that it must be applied at a point above the entrance of all foul-air flues. In the first plan it will usually be found most convenient to apply the accelerating heat by means of a coil of pipe lining the shaft and heated by steam.*

The difference in the cost of maintenance for systems *one*, *two*, and *three* has been computed by Planat for a building four stories high, having a ventilation of thirty-nine cubic feet per second.

He finds that with system *one* it would be necessary to burn 7 pounds of coal per hour to heat the shaft; with system *two*, 5½ pounds, and with system *three*, 4⅒ pounds. The *third* system is therefore much the least costly of the three as regards maintenance, and it also secures greater uniformity of action, and is more con[illegible]re, for which reasons it should in most cases be pre[illegible]

*See also table No. [illegible]

DISTRIBUTION OF AIR.*

"Too much care cannot be taken in the matter of the distribution of air supplied by systems of ventilation. In halls of audience, where the occupants are at rest, any slight inequality in distribution is noticeable; but in workshops, where the occupants are continually in motion, and not in close contact with each other, less care is generally required in the matter. Experiment has shown that a velocity of air less than nineteen inches per second is not perceptible to the senses, and that a velocity as high as three feet per second is not objectionable. Hence especial care should be exercised in order that no current having a velocity of over three feet per second, or one hundred and eighty feet per minute, be allowed to come in contact with the body. This naturally requires careful designing of the main and distributing ducts. Systematic supply involves arrangements of ducts and passages by which the outer air, from some chosen point, shall be transported to certain desirable mouths of delivery or outlet registers.

"The velocity can be gradually reduced by an increase in the relative area between branches and main passages, and further by the area of the outlets, until the final velocity, as it meets the body, does not exceed 180 feet per minute. A safe rule is to make the total area of branches (before they enter the delivery registers, if such be supplied) never less than 25 per cent in excess of the area of the main passage, and as much greater as may be required to properly reduce the velocity.

"Outlet flues should be made about one and a half times the area of supply flues and branches, and placed in such positions as to compel a perfect distribution of the air. If made too small, the air will find other and easier exits. With a given volume of air moved, a low velocity results in very little loss of pressure by friction, but requires large passages; while a high velocity entails a decided loss by friction, with a marked decrease in area of passages.

"Between these two extremes of loss and gain, a fair average must be taken. This may be attained by allowing a velocity of from six to twelve hundred feet per minute for main and distributing ducts. Much higher velocity may be required under some circumstances, as when the apparatus is not large enough for the work.

"The dimensions to be given these ducts or passages are absolute ones when the quantity of air to be moved shall have been established by the number of persons and their supply, and when the velocity of the movement of the air is determined or accepted. The velocity of movement is limited on one hand by the motive power applied to impel the air, and on the other by practical dimensions of the ducts accepted in the construction and passages."

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* B. F. Sturtevant Circular, 1888.

TABLE No. 30.

AREAS OF FLUES AND DUCTS TO CONVEY AIR TO DIFFERENT NUMBERS OF PERSONS, AT STATED VELOCITIES.*

Cubic Feet of Air per Hour.	Air per Capita per Hour.				Velocity of Air.—Feet per Second.					
	3,000	1,800	1,200	600	3	5	8	12	15	20
	Air per Minute.				Velocity per Minute.					
	50	30	20	10	180	300	480	720	900	1,200
	Approximate No. of Persons Supplied with Air.				Area of Pipe or Duct in Square Inches (÷ 144 = Sq. Ft.).					
5,000	2	3	4	8	67	40	25	17	13	10
10,000	3	6	8	17	133	80	50	33	27	20
20,000	7	10	17	33	267	160	100	67	53	40
30,000	10	17	25	50	400	240	150	100	80	60
40,000	13	22	33	67	533	320	200	133	107	80
50,000	17	28	42	83	667	400	250	167	133	100
60,000	20	33	50	100	800	480	300	200	160	120
70,000	23	39	58	117	933	560	350	233	187	140
80,000	27	44	67	133	1,067	640	400	267	213	160
90,000	30	50	75	150	1,200	720	450	300	240	180
100,000	33	56	83	167	1,333	800	500	333	267	200
200,000	67	111	167	333	2,667	1,600	1,000	667	533	400
300,000	100	167	250	500	4,000	2,400	1,500	1,000	800	600
400,000	133	222	333	667	5,333	3,200	2,000	1,333	1,067	800
500,000	167	278	417	833	6,667	4,000	2,500	1,667	1,333	1,000
600,000	200	333	500	1,000	8,000	4,800	3,000	2,000	1,600	1,200
700,000	233	389	583	1,167	9,333	5,600	3,500	2,333	1,867	1,400
800,000	267	444	667	1,333	10,667	6,400	4,000	2,667	2,133	1,600
900,000	300	500	750	1,500	12,000	7,200	4,500	3,000	2,400	1,800
1,000,000	333	556	833	1,667	13,333	8,000	5,000	3,333	2,667	2,000
A	B	C	D	E	F	G	H	I	J	K

OPENINGS TO SUPPLY THE AIR REQUIRED. — If we consider 1,800 cubic feet of air as a fair average for pupils of all ages, we shall have for fifty pupils, 90,000 cubic feet. This will be a demand of 1,500 cubic feet per minute; and at a velocity of 5 feet per second, we shall require an opening and pipe of 720 square inches clear area, and the same for the discharge air. There should be at least two inlets and two discharges of 360 square inches each.

If, as many persons estimate, the amount [illegible] exceed this, or 3,000 cubic feet for each pupil per hour, then the area of the inlets [illegible] be increased also, since it is not practicable to largely increase the velocity [illegible] air. For other velocities than noted, the area of the flue in square inches [illegible] total discharge required per hour in hundreds of cubic feet, and divided by [illegible] nd.

TABLE No. 31. B. F. S., 1873.

THE DIAMETERS OF AIR PIPES, WITH PROPER ALLOWANCES FOR FRICTION.

To find from the Table how many pipes of smaller diameter will convey at a given pressure the same amount of air as one of greater diameter, find the diameter of the large pipe in first vertical column, and follow along horizontally until reaching the column headed by the diameter of the small pipes.

DIAMETERS OF BRANCH PIPES IN INCHES.

Diam. of Large Pipe.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
2	5.7																	
3	16	2.7																
4	32	5.7	2.0															
5	56	9.8	3.6	1.8														
6	88	16	5.7	2.8	1.6													
7	129	23	8.3	4.1	2.3	1.5												
8	180	32	12	5.7	3.2	2.1	1.4											
9	244	42	16	7.6	4.3	2.8	1.9	1.3										
10	317	56	20	9.9	5.7	3.6	2.4	1.7	1.3									
11	402	71	26	12	7.0	4.5	3.1	2.2	1.7	1.3								
12	501	88	32	16	9.0	5.7	3.8	2.8	2.0	1.6	1.2							
13	613	107	39	19	11	6.9	4.7	3.4	2.5	1.9	1.5	1.2						
14	737	129	47	23	13	8.3	5.7	4.1	3.0	2.3	1.8	1.5	1.2					
15	876	152	56	27	16	9.9	6.7	4.8	3.6	2.8	2.2	1.8	1.4	1.2				
16	1026	180	65	32	18	11	7.9	5.7	4.2	3.2	2.6	2.1	1.7	1.4	1.2			
17	1197	208	76	37	21	13	9.2	6.6	4.9	3.8	2.9	2.4	2.0	1.6	1.4	1.2		
18	1375	239	88	43	24	16	10	7.7	5.7	4.3	3.4	2.8	2.3	1.9	1.6	1.3	1.2	
19	1580	275	100	49	28	18	12	8.8	6.5	5.0	3.9	3.2	2.6	2.2	1.8	1.5	1.3	1.2
20	1797	313	114	56	32	20	14	9.9	7.4	5.7	4.5	3.6	2.9	2.5	2.1	1.7	1.5	1.3
22	2284	398	145	71	41	26	18	13	9.3	7.2	5.7	4.5	3.7	3.1	2.6	2.2	1.9	1.7
24	2834	493	180	88	50	32	22	16	12	8.9	7.6	5.7	4.6	3.8	3.2	2.9	2.4	2.1
26	3474	605	219	108	62	39	27	19	14	11	8.6	6.9	5.7	4.7	4.0	3.4	2.9	2.5
28	4165	725	265	129	74	48	32	23	17	13	10	8.3	6.8	5.7	4.8	4.1	3.5	3.0
30	4963	864	315	154	88	56	38	28	20	16	12	9.9	8.0	6.7	5.7	4.7	4.1	3.6
36	7818	1361	497	243	139	88	60	43	32	25	19	16	13	11	8.9	7.6	6.5	5.7
41	11488	2000	730	358	205	129	88	63	47	36	29	23	19	16	13	11	9.6	8.5
48	15989	2792	1081	492	282	180	123	88	66	50	39	32	26	22	18	16	13	12

NUMBER OF PIPES OF DIFFERENT SIZES HAVING THE SAME TOTAL AREA OF CROSS SECTION.

The frictional resistance to the flow of gases (at the same velocity) in straight pipes of different sizes is ***inversely*** proportional to their diameters.

DIAMETERS OF THE SMALLER PIPES.

Diam in Ins.	¼	⅜	½	¾	1	1¼	1½	2	2½	3	4	5	6	7	8	10
1	16	7	4													
1¼	25	11	6	3												
1½	36	16	9	4	2											
2	64	28	16	7	4	2½										
2½	100	44	25	11	6	4	3									
3	144	64	35	16	9	6	4	2								
4	256	114	64	28	16	10	7	4	2½							
5	400	177	100	44	24	16	12	6	4	3						
6	576	256	144	64	36	24	16	9	6	4	2					
7	784	348	196	87	49	31	21	12	8	5	3	2				
8	1,024	456	256	112	64	40	28	16	10	7	4	2½	2			
10	1,600	711	400	177	100	64	44	25	16	11	6	4	3	2		
12	2,304	1,024	576	256	144	96	64	36	24	16	8	6	4	3	2	
16	4,096	1,824	1,024	448	256	160	112	64	40	28	16	10	7	5	4	2½
24	9,216	4,096	2,304	1,024	576	384	256	144	96	64	32	24	16	12	9	6
30	14,400	6,400	3,600	1,600	900	576	400	222	144	100	55	36	25	18	14	9
36	20,761	9,216	5,190	2,304	1,297	829	576	324	207	144	81	52	36	26	20	13
42	28,224	12,544	7,056	3,136	1,764	1,129	784	441	282	196	110	70	49	36	28	17½
48	36,864	16,384	9,216	4,096	2,304	1,536	1,024	576	384	256	144	96	64	47	36	23

TABLE No. 32.

Diameter of a Circle X 3.1416 = the Circumference.
Circumference of a Circle X .31831 = the Diameter.

○ Diameters, Circumferences, and Areas of Circles. □

Side of a Square X 1.128 = Diameter
Square of Diameter X .7854 = the Area o

Diam. Ins.	Circum. Ins.	Area. Sq. Ins.
1/16	.19635	.00307
1/8	.3927	.0122
1/4	.7854	.0490
3/8	1.1781	.1104
1/2	1.5708	.1963
5/8	1.9635	.3068
3/4	2.3562	.4417
7/8	2.7489	.6013
1 in.	3.1416	.7854
1/8	3.5343	.9940
1/4	3.9270	1.2271
3/8	4.3197	1.4848
1/2	4.7124	1.7671
5/8	5.1051	2.0739
3/4	5.4978	2.4052
7/8	5.8905	2.7611
2 ins.	6.2832	3.1416
1/4	7.0686	3.9760
1/2	7.8540	4.9087
3/4	8.6394	5.9395
7/8	9.0321	6.4918
3 ins.	9.4248	7.0686
1/4	10.210	8.2957
1/2	10.995	9.6211
3/4	11.781	11.044
7/8	12.173	11.793

Diam. Ins.	Circum. Ins.	Area. Sq. Ins.	Diam. Ins.	Circum. Ins.	Area. Sq. Ins.	Diam. Ins.	Circum. Ins.	Area. Sq. Ins.	Diam. Ins.	Circum. Ins.	Area. Sq. Ins.	Diam. Ins.	Circum. Ins.	Are. Sq. In
4 ins.	12.566	12.566	10 ins.	31.416	78.540	16 ins.	50.265	201.062	22 ins.	69.115	380.133	28 ins.	87.964	615.753
1/4	13.351	14.186	1/4	32.201	82.516	1/4	51.051	207.394	1/4	69.900	388.822	1/4	88.750	626.798
1/2	14.137	15.904	1/2	32.986	86.590	1/2	51.836	213.825	1/2	70.686	397.608	1/2	89.535	637.941
3/4	14.922	17.720	3/4	33.772	90.762	3/4	52.621	220.353	3/4	71.471	406.493	3/4	90.321	649.182
5 ins.	15.708	19.635	11 ins.	34.557	95.033	17 ins.	53.407	226.980	23 ins.	72.256	415.476	29 ins.	91.106	660.521
1/4	16.493	21.647	1/4	35.343	99.402	1/4	54.192	233.705	1/4	73.042	424.557	1/4	91.891	671.958
1/2	17.278	23.758	1/2	36.128	103.869	1/2	54.978	240.528	1/2	73.827	433.731	1/2	92.677	683.494
3/4	18.064	25.967	3/4	36.913	108.434	3/4	55.763	247.450	3/4	74.613	443.014	3/4	93.462	695.128
6 ins.	18.849	28.274	12 ins.	37.699	113.097	18 ins.	56.548	254.469	24 ins.	75.398	452.390	30 ins.	94.248	706.860
1/4	19.635	30.679	1/4	38.484	117.859	1/4	57.334	261.587	1/4	76.183	461.864	1/4	95.033	718.690
1/2	20.420	33.183	1/2	39.270	122.718	1/2	58.119	268.803	1/2	76.969	471.436	1/2	95.818	730.618
3/4	21.205	35.784	3/4	40.055	127.676	3/4	58.905	276.117	3/4	77.754	481.106	3/4	96.604	742.644
7 ins.	21.991	38.484	13 ins.	40.840	132.732	19 ins.	59.690	283.529	25 ins.	78.540	490.875	31 ins.	97.389	754.769
1/4	22.776	41.282	1/4	41.626	137.886	1/4	60.475	291.039	1/4	79.325	500.741	1/4	98.175	766.992
1/2	23.562	44.178	1/2	42.411	143.139	1/2	61.261	298.648	1/2	80.110	510.706	1/2	98.968	779.313
3/4	24.347	47.173	3/4	43.197	148.489	3/4	62.046	306.355	3/4	80.896	520.769	3/4	99.745	791.732
8 ins.	25.132	50.265	14 ins.	43.982	153.938	20 ins.	62.832	314.160	26 ins.	81.681	530.930	32 ins.	100.531	804.249
1/4	25.918	53.456	1/4	44.767	159.485	1/4	63.617	322.063	1/4	82.467	541.189	1/4	101.316	816.865
1/2	26.703	56.745	1/2	45.553	165.130	1/2	64.402	330.064	1/2	83.252	551.547	1/2	102.102	829.578
3/4	27.489	60.132	3/4	46.338	170.873	3/4	65.188	338.163	3/4	84.037	562.002	3/4	102.887	842.390
9 ins.	28.274	63.617	15 ins.	47.124	176.715	21 ins.	65.973	346.361	27 ins.	84.823	572.556	33 ins.	103.672	855.30
1/4	29.059	67.200	1/4	47.909	182.654	1/4	66.759	354.657	1/4	85.608	583.208	1/4	104.458	868.30
1/2	29.845	70.882	1/2	48.694	188.692	1/2	67.544	363.051	1/2	86.394	593.958	1/2	105.243	881.41
3/4	30.630	74.662	3/4	49.480	194.828	3/4	68.329	371.543	3/4	87.179	604.807	3/4	106.029	894.61

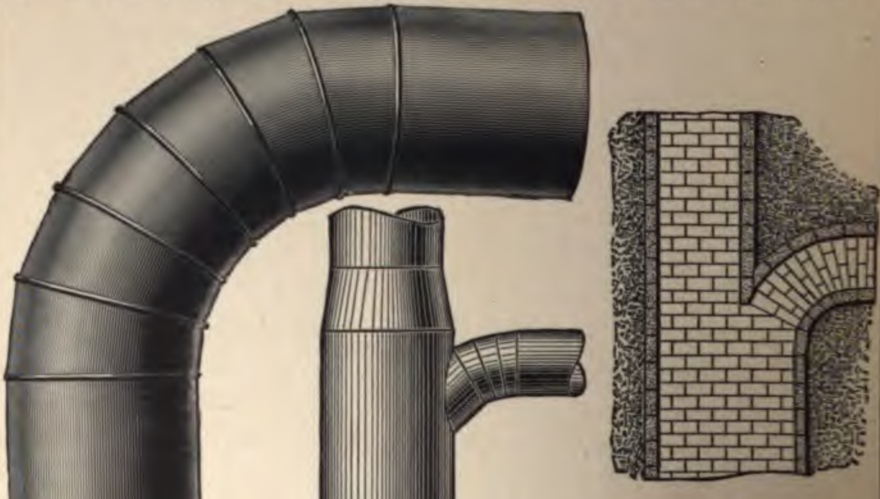
TABLE No. 33.

WEIGHTS OF GALVANIZED IRON PIPE IN POUNDS PER RUNNING FOOT.*

Diam. of Pipe in inches.	GAUGE OF IRON.					Diam. of Pipe in inches.	GAUGE OF IRON.				
	No. 24.	No. 22.	No. 20.	No. 18.	No. 16.		No. 24.	No. 22.	No. 20.	No. 18.	No. 16.
4	1½	1⅝	2	2¾	3¼	28	9½	11¾	14	18	21½
5	1⅞	2	2½	3⅜	4	30	10	12¼	15	19⅜	23
6	2⅛	2½	3	4	4¾	32	..	13⅛	16	20¾	24½
7	2½	3	3½	4⅝	5½	34	..	14	17	22¼	26¼
8	2⅞	3⅜	4	5¼	6¾	36	..	15	18	23¾	27¾
9	3¼	3¾	4½	5⅞	7	38	..	16	19	24½	29½
10	3½	4	5	6½	7¾	40	..	17	20	26¼	31¼
11	3¾	4½	5½	7	8¼	42	..	..	21	28	33
12	4	4⅞	6	7½	9	44	..	..	22	29¾	35
13	4¼	5⅛	6½	8⅜	10	46	..	..	23	31½	37
14	4⅝	5½	7	9	11	48	..	..	24	33¼	39
15	5	6	7½	9⅝	12	50	..	..	25	35	41
16	5½	6½	8	10¼	13	52	..	..	26	36¾	43
18	6	7¼	9	11½	14¼	54	..	..	27	38½	45
20	6½	8	10	12¾	15½	56	..	..	28	40¼	47
22	7¼	8¾	11	14	16¾	58	..	..	29	42	49
24	8	9⅝	12	15¼	18½	60	..	..	30	43¾	51
26	8¾	10½	13	16½	20						

For general ventilating purposes, pipes under 10 inches should be No. 24 gauge; 10 to 15 inches, No. 22; 15 to 24 inches, No. 20; over 24 inches, No. 18 gauge.

PROPER CONSTRUCTION OF GALVANIZED IRON AND BRICK VENTILATING FLUES.



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*From B. F. Sturtevant's circular of 1889.

CHAPTER XXIX.

MECHANICAL OR POWER VENTILATION.

THE BEES FURNISH A PRACTICAL EXAMPLE.*

"IMAGINE a dome-shaped building, perfectly tight except through a small hole at the bottom, capable of containing thirty or forty thousand animals full of life and activity, every portion of the enclosed space that can be spared being filled with curious machinery — the problem is, how to warm and ventilate such a space so as to maintain a proper temperature, and yet to give to every individual within it a proper supply of air.

"Now, this is the condition of a common beehive; and, if with all our machines and contrivances and scientific resources, the combined operation of warming and ventilating a room be difficult or unsatisfactory, how infinitely more so must be that of a small beehive, crowded with bees, the greater part of the interior filled up with combs of waxen cells, and only one small opening for the ingress and egress of the inhabitants, or for the escape of foul air and the entrance of fresh!

"It must not be supposed that, because the vitality of insects is greater than that of warm-blooded animals, bees are not affected by the same agencies which affect us, for they are so, and in a similar manner. They fall down apparently dead if confined in a close vessel; they perish in gases which destroy us; they perspire and faint with too much heat, and are frozen to death by exposure to too much cold.

"When from any circumstance, such as exposure to the sun, overcrowding, or the excitement produced by fear, anger, or preparation for swarming, the temperature of the hive is greatly raised, the bees evidently suffer. They often perspire so copiously as to be drenched with moisture; and on fine summer nights thousands of them may be seen hanging out in festoons and clusters for the purpose of relieving the crowded state of the hive.

"On inquiring into the method ado[illegible]es for renewing the air of the hive, Huber was struck [illegible] appearance of a number of the workers arranged [illegible]ntrance hole, a little within the hive, incessantly [illegible]eir wings.

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* Tomlinson, "Warr[illegible]

"The worker bees perform the office of ventilators, and the number at one time varies from eight or ten to twenty or thirty, according to the state of the hive and the heat of the weather. I have frequently watched their proceedings with interest. They station themselves in files just within the entrance of the hive, with their heads towards the entrance, while another and a larger party stand a considerable way within the hive with their heads also towards the entrance.

"They plant their feet as firmly as possible on the floor of the hive, stretching forward the first pair of legs, extending the second pair to the right and the left; while the third, being placed near together, are kept perpendicular to the abdomen, so as to give that part a considerable elevation; then uniting the two wings of each side by means of the small marginal hooks with which they are provided, so as to make them present as large a surface as possible to the air, they vibrate them with such rapidity that they become almost invisible. The two sets of ventilators, standing with their heads opposed to each other, thus produce a complete circulation of the air of the hive, and keep down the temperature to that point which is fitted to the nature of the animal.

"The laborious task of ventilating the hive is seldom or never intermitted in the common form of hive either by day or by night during summer. There are separate gangs of ventilators, each gang being on duty about half an hour. In winter, when the bees are quiet and their respiration only just sufficient to maintain vitality, the ventilating process is not carried on; but, by gently tapping on the hive, its inmates wake up, increase the number of their respirations, and consequently the temperature of the hive to such a degree, that the air becomes intolerably hot and vitiated. To remedy this a number of worker bees go to the entrance of the hive and begin to ventilate the interior as laboriously as in summer, although the open air be too cold for them to venture out. By this process the bees also get rid of noxious odors in the hive.

"In order to see what effect a similar fanning would produce on the air of a glass receiver containing a lighted taper, M. Senebier advised the construction of a little artificial ventilator, consisting of eighteen tin vanes. This was put into a box, on the top of which was adapted a large cylindrical vessel of the capacity of 3,000 cubic inches.

"A lighted taper contained in this vessel was extinguished in eight minutes; but, on restoring the air and setting the ventilator in motion, the taper burnt brilliantly, and continued to do so as long as the vanes were kept moving. On holding small pieces of paper suspended by threads before the aperture, the existence of two currents of air became evident; there was a current of hot air rushing out, and at the same time a current of cold air passing in."

The problem of setting in motion quantities of air sufficient to supply the requirements of ventilation, and so to direct this air as to secure a maximum of movement with a minimum of expended power, is a mechanical problem that becomes important, both from the standpoint of work accomplished and economy of doing it.

In the system of forced circulation by means of that universally adopted machine,—a fan or blower,—the action is absolute and positive. Mr. Briggs states that: "In all mechanical appliances, that is simplest that most directly and positively effects the purpose in view; and, in this matter of supplying air, it may be claimed that the process of impelling it, when and where wanted, is at once the most certain and efficient, and that the fan (in its form of a rotating wheel with vanes for large uses) is the simplest and readiest machine for impelling air."

The whole matter cannot be better expressed than in the words of the late Robert Briggs, a man of large experience in practical ventilation and heating: "It will not be attempted at this time to argue fully the advantages of the method of supplying air for ventilation by impulse through mechanical means — the superiority of forced ventilation, as it is called. This mooted question will be found to have been discussed, argued, and combated on all sides, in numerous publications; *but the conclusion of all is that, if the air is wanted in any particular place, at any particular time, it must be put there.*

"Other methods will give results at certain times and seasons, or under certain conditions. One method will work perfectly with certain differences of internal and external temperatures, while another method succeeds only when other differences exist. One method reaches to relative success whenever a wind can render a cowl efficient. Another method remains perfect as a system if no person opens a door or window. No other method than that of impelling air by direct means with a fan, is equally independent of accidental conditions, equally efficient for a desired result, or equally controllable to suit the demands of those who desire ventilation.

"On the other hand, when the air is forced in, its quality, temperature and point of admission are completely under control; in a word, the method is *positive;* all spaces are filled with air under a slight pressure, and the leakage is outward, preventing the drawing of polluted air into the room from any source."

We shall see in the following pages how fast air must pass through a flue in order to supply the requirements of respiration. We have also seen that this current must be properly distributed and be of a certain temperature and humidity. Now these conditions are approached in different degrees by d [illegible] stems of heating and ventilating; *but in no system has th [illegible] without the aid of mechanical means.*

As applied to theatres and halls of assembly, the fan is usually employed for forcing the air into the room on what is called the plenum system, and instances of its application in this way will be found in the House of Representatives, in Washington, and in the Vienna, Frankfort, and the Madison Square Theatre, New York, to which further reference will be made.

Arranged for hospital ventilation, the great utility of the fan lies in the power which it gives to rapidly flush the wards morning and evening with large quantities of air. The effects thus produced are shown in the Barnes Hospital.

In some of the larger insane asylums of this country, the propelling fan is used as a constant source of power, as, for example, in the New York Asylum at Utica, where two fans are employed for this purpose. Each of these fans is twelve feet in diameter, having a cross sectional area at the point of delivery of a little over forty square feet.

About 1846 J. J. Walworth & Co. employed mechanical ventilation in the Boston Custom House, using a fan turned by a steam engine. This was, perhaps, the first attempt of the kind in this country. The next fan-work was at the Utica, N. Y., Insane Asylum. These fans were made with radial blades at right angles to the axis of rotation.

In the year 1855 Mr. Nason was associated with Gen. Meigs and Mr. Robert Briggs in experiments connected with the warming and ventilation of the Capitol at Washington.

Of the later operations of the Walworth Manufacturing Company in the line of steam heating and ventilation, we need hardly refer, since their distinctive work is well known from the State of Maine to Texas, from the Atlantic to the Pacific Oceans.

As, however, this line of public work has for the last twenty years been under one chief direction and superintendence, a brief personal reference is in order, as the writer has had much pleasant and profitable exchange of ideas and methods with this educated and progressive engineer.

Levi F. Greene, M. E., had a liberal education and a full apprenticeship at the works of George Corliss, Providence, R. I., had seen also several years' service as chief engineer in the United States Navy, before and during the Civil War. He engaged with the Walworth Company in 1869, and soon after took charge of the outside operations, or those directly involving the warming by steam and ventilating large public buildings. Of the many institutions so heated, we can note only a few, beginning with the *Buffalo City and County Hall*, 1873; *Hospital for the Insane, Columbus, O., and Pontiac, Mich.; Michigan State Capitol, Lansing, and Agricultural College; Ionia State Prison, Peoria County Court House, Illinois; John Shillito Building, Cincinnati, O.; Iowa State House, Des Moines, Ia.; Hospital for the Insane, Austin, Tex., and Elgin, Ill.; Indiana State House, Ind.; Southern Hotel, Turner Building, and Comstock Building, St. Louis; Westtown Boarding School, offices Lehigh Valley Railroad, Pa.; Memorial Church, South Bethlehem, Pa.*

There are hundreds of lesser institutions, corporations, and industrial structures. These, however, have been referred to in our mention of the Overhead Steam System, Chapter XXII., pages 398–401.

For proportions of these fans and power required, see table No. 35½, page 557.

While it is not the writer's intention to attempt any general review or analysis of the several machines which have been employed, and are now used for the propulsion and supply of air under pressure for commercial and general uses, some attention will, however, be given to the class of disk wheels and fans best adapted to supply large volumes of air at the low pressure and velocity required in systems of heating, drying, and ventilation, this being in a measure necessary as an introduction and explanation of the fan designed and used by the author, and as forming a basis of comparison between the cost of any air movement in chimneys or flues produced by heat, and an equal supply of air by mechanical methods.

This is really the vital point in all ventilating operations. The experiments of the author have been tabled, and the views of several able and practical engineers brought to bear on the matter.

Of *propellers* for moving air, many kinds have been used, among which may be mentioned those of Combes, Rittenger, Hales, Howorth, Roots, Chaplin, Lloyd, Wing, Hope, and Blackman. Most of these are in some form of revolving disk; the floats are so placed as to set in motion the air outward radially, thereby creating a partial evacuum near the axis.

The object of any fan is not only to set in motion large quantities of air, but to set it in motion in such a manner as not to produce loss by opposing counter-currents and by useless friction.

Air, on account of its extreme mobility, requires primarily very little power to move it; but when it is forced through small apertures, or set in motion in such a way as to produce cross currents, great power may be required to accomplish a little work.

Without intending any adverse criticism on this useful class of ventilating wheels that have done so much efficient work, in all kinds of places and conditions, it yet seems entirely within the scope of our inquiry into ways and means of moving air to note the peculiar and distinctive condition under which all disk and cone wheels do their work, and the possibility of securing still more favorable results, especially where large volumes of air are required, at little or no pressure.

In the construction of all radial, or screw-bladed fans moving the air parallel to the rotating shaft, but small blade area can be secured with any given diameter of wheel, since, in dividing the plane of any circle radially from the centre, area of blade is obtained only as we leave the centre, and attain distance from it, thereby securing an increasing velocity as we approach the periphery and larger blades, due to the larger circle.

Dividing the whole plane of any disk wheel into three circles or areas, it will be seen that the first circle around the shaft is of little or no value except as space for the shaft hub and heels of the blades. Suppose this wheel to be of six feet diameter, the space bounded by a circle one foot around the centre is practically useless; the next portion of the circle, one foot wide around the first circle, is really the first effective area for blade duty; while the next plane or circle of one foot (outside diameter six feet) has four times the value of the last, all this owing to the increasing velocity, due to the distance from the centre, or dead point, and regardless of the number, form, or pitch of the blades. It was doubtless a consideration of these facts that led Blackman to increase his blade surface at the point of greatest diameter and efficiency. That blade area in a fan wheel represents piston area in the steam engine or pump, should go without saying, also, that reduced piston or fan blade area means loss of efficiency and unnecessary increase of power to accomplish a stated duty.

In the circular of the manufacturers (Howard and Morse) the claim is made for great additional feed area due to this end flange, and drawings are given to show the amount and effect of this end feed, also the absence of a practical feed area in a *blast fan of entirely different construction*. Whatever may be the real utility and value of this curving the end of the blade, this comparison and illustration does not seem a fair one, since, if any such wheel as the one shown (inlet six and one-fourth square feet, outlet *three-fourths of one foot*) was ever made, it was not designed for the same uses as the wheel compared with it.

At the same time it is clear that increased blade area at the periphery of a disk wheel is an effort in the right direction, since it has been extensively copied by other wheel manufacturers and as extensively objected to by the owners of the Blackman wheel.

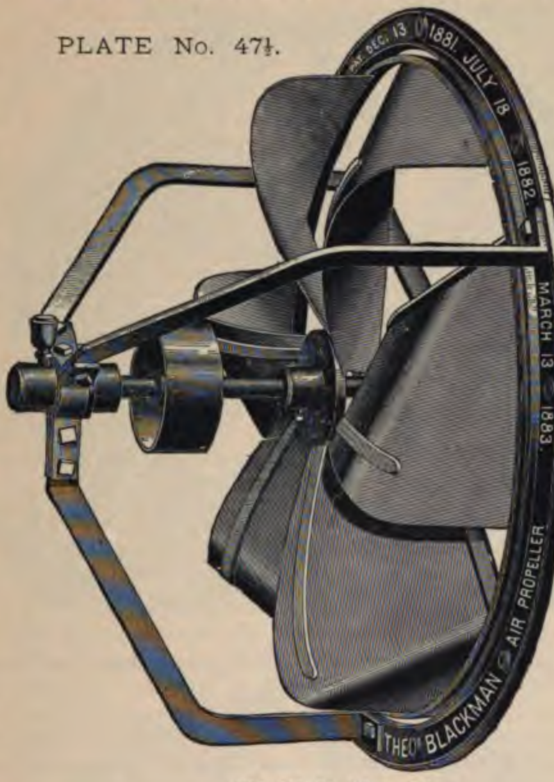
On the following pages will be found two examples of air propellers, the Blackman "peripheral flange" and the Wing disk. These are shown as representing the best features of this distinctive class of ventilating wheels.

The principal claims for the Wing disk are simplicity of construction, light weight, and thus economy of power. The blades are curved and have an expanding pitch, thereby increasing the amount of air moved, and thus also reduce the "slippage." The blades are adjustable, and may be set to suit the conditions under which the fan is to operate, and the currents of air can be reversed without changing the fan, belt, or pipes.

In the Blackman wheel the distinctive and principal advantage is the form and construction of the blades, by which greater strength and stiffness is secured. For efficiency, see page 554.

THE BLACKMAN AIR PROPELLER.

PLATE No. 47½.


PAT. DEC. 13 1881. JULY 18 1882. MARCH 13 1883.
THEO. BLACKMAN AIR PROPELLER

HEATING AND VENTILATING MACHINERY,
ELECTRIC AND WATER MOTORS, ENGINES, ETC.

D. P. GOSLINE, NEW ENGLAND AGENT,
—SUCCESSOR TO—
NEW YORK EXHAUST VENTILATOR CO.,
No. 32 OLIVER STREET, BOSTON

TABLE No. 34.

VOLUME OF AIR DISCHARGED AND POWER REQUIRED.

Revolutions per Minute.	CUBIC FEET OF AIR PER MINUTE, FREE DELIVERY.						HORSE POWER REQUIRED, FREE DELIVERY.					
	30-in. $90.00	36-in. $100.00	42-in. $125.00	48-in. $150.00	60-in. $275.00	72-in. $300.00	30-in.	36-in.	42-in.	48-in.	60-in.	72-in.
200..	....	....	....	16,256	31,750	54,864	.....	.....	.....	.28	.87	2.16
225..	....	....	....	18,288	35,719	61,722	.....	.....	.....	.40	1.24	3.08
250..	....	....	13,613	20,320	39,688	68,580	.....	.....	.28	.56	1.70	4.22
275..	....	....	14,974	22,352	43,657	75,438	.....	.....	.38	.74	2.26	5.62
300..	....	10,287	16,335	24,384	47,625	82,296	....	.23	.49	.96	2.93	7.29
350..	6,945	12,002	19,058	28,448	55,562	96,012	.15	.36	.78	1.52	4.65	11.58
400..	7,938	13,716	21,780	32,512	63,500	109,728	.22	.54	1.17	2.28	6.94	17.28
450..	8,930	15,431	24,503	36,576	71,438	123,444	.31	.77	1.66	3.24	9.89	24.61
500..	9,922	17,145	27,225	40,640	79,375	137,160	.42	1.05	2.28	4.45	13.56	33.75
550..	10,914	18,860	29,948	44,704	87,313	....	.56	1.40	3.04	5.90	18.05	.....
600..	11,906	20,574	32,670	48,768	95,250	....	.73	1.82	3.94	7.86	23.44	.....
700..	13,891	24,003	38,115	56,896	....	....	1.16	2.89	6.25	12.20	.....	.....
800..	15,875	27,432	43,560	65,024	....	....	1.74	4.32	9.33	18.21	.....	.....
900..	17,860	30,861	49,006	....	....	....	2.47	6.15	13.29	.....	.....	.....
1,000..	19,844	34,290	54,451	....	....	....	3.39	8.44	18.23	.....	.....	.....
1,100..	21,828	37,719	....	....	....	....	4.51	11.23	.....	.....	.....	.....
1,200..	23,813	41,148	....	....	....	....	5.86	14.58	.....	.....	.....	.....
1,300..	25,797	....	....	....	....	....	7.45	.....	.....	.....	.....	.....

NOTE.—See Geo. A. Suter's experiments (table No. 35).

TABLE No. 35.

EXPERIMENTS WITH A 48-INCH BLACKMAN FAN, WITH STEAM POWER.

G. A. SUTER, M. E.

A	B	C	D	E	F	G	H	I	J	K
							EFFECT.			
Revolutions per minute.	Veloc. of air. Ft. per second. C÷753.6	Cubic ft. of air per minute.	Pounds of air per minute. C x .075	Pressure Water Gauge, Inches.	Horse power.	Work done by Engine. Ft. Lbs. per minute. F x 33,000	Setting air in motion. Ft. Lbs. per minute. $B^2 \div 64.4 \times D$	Overcoming pressure. Ft. Lbs. per min. 5.2 x E x C.	Total Ft. Lbs. per minute. H + I	Efficiency or percentage of power utilized. J ÷ G x 100
340	27.	20,372	1,528		0.76	25,080	17,266		17,266	69 Av., 56%
453	35.4	26,660	2,000		1.99	65,670	39,000		39,000	59
536	42.	31,649	2,374		3.86	127,380	65,048		65,048	51
627	48.5	36,543	2,741		6.47	213,510	100,046		100,046	47
Forcing air through 30 ft. of 48-inch pipe, on outlet side of the Fan.										
340	13.2	9,983	749	0.28	1.12	36,960	2,022	14,575	16,597	45 Av., 38%
430	17.3	13,017	976	0.47	3.17	104,610	4,538	31,761	36,299	35
534	22.6	17,018	1,276	0.75	6.07	200,310	10,119	66,370	76,489	38
570	24.7	18,649	1,399	0.87	8.46	279,180	13,286	84,193	97,479	35
Drawing air through 30 ft. of 48-inch pipe, on the inlet side of Fan, the pipe being obstructed by a diaphragm of cheese-cloth.										
330	11.1	8,399	630	0.26	1.31	43,230	1,197	11.353	12,552	29 Av., 26%
437	13.4	10,071	755	0.45	3.27	107,910	1,986	23,566	25,552	24
516	14.8	11,157	837	0.75	6.00	198,000	2,846	45,072	47,918	24
Forcing air through 30 ft. of 48-inch pipe, on outlet side of Fan, the pipe being obstructed by a diaphragm of cheese-cloth.										

Regarding the final issue of the real efficiency of this class of fans of more than passing interest, we may glance at some other conditions and results not shown in the preceding table (taken from the Blackman circular). This shows, as seen, the volume of the air per minute, and the horse-power required to simply keep the wheel in motion, at the various speeds stated — this being one of the conditions under which such wheels are often placed, as when transferring the air from one side of a partition to the other, exhausting air from a dining or dry room to the outer air.

In the first four experiments, the only resistance to the flow of the air was the frictional resistance of the tube and the fan passages, and the resistance caused by the contracted vein at the entrance. In the second two sets, the passage of the air was obstructed by a diaphragm of cheese-cloth placed within the tube; and this additional resistance was ascertained by a water gauge in the usual way.

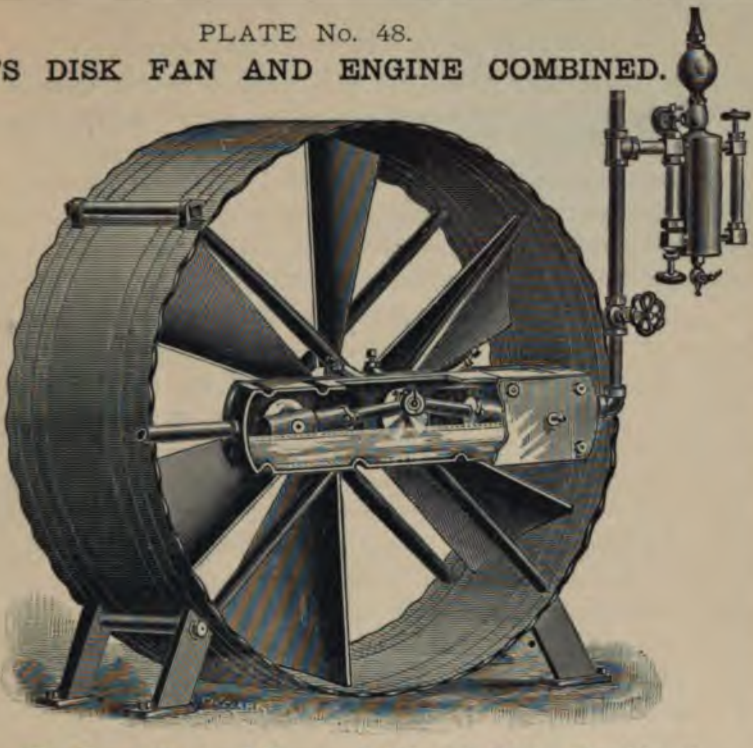
It is often necessary, however, to move the air a certain distance before it can be discharged. In such cases the air is gathered and conducted away in pipes. If of large area and entirely unimpeded, it would seem that such delivery might be termed free; but we soon see that it is not so, as even a pipe 30 feet long and 48 inches in diameter imposes a certain and definite load on the wheel, and such load increases as the pipe is lengthened or obstructed, as the air would be in a system of pipes arranged for ventilating a building.

Condensing the results shown by both tables, we may note that, for a movement of air simply off the blades of the wheel, the relation of power required to air moved may be as high as 70 per cent. That when gathering the air and discharging through an open pipe 30 feet long, the efficiency falls to 56 per cent, or nearly one fifth less than in the former case. Obstructing the pipe on the inlet side of the fan to the extent of 0.28 inches of water pressure, we find that the *efficiency falls to* 38 *per cent*, while by forcing against the same obstruction, the efficiency falls *to* 26 *per cent, and thus the total average efficiency for these three conditions and eleven different experiments is* 40 *per cent, and this agrees substantially with the writer's experiments with the Centrifugal and Disk Wheels (Table No.* 38) except that the wheels employed being smaller, 2 feet in diameter, showed a somewhat less efficiency. For power to operate other wheels, see tables Nos. 35½ and 36.

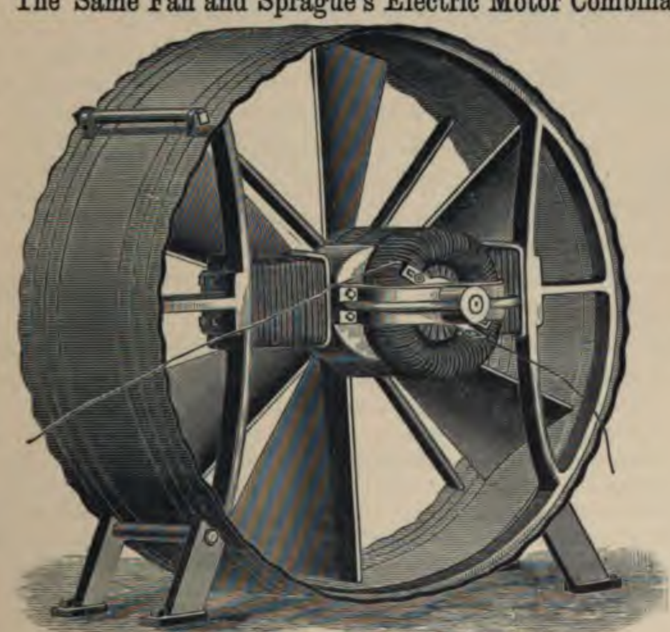
PLATE No. 48.

WING'S DISK FAN AND ENGINE COMBINED.

Wing's Disk Fan has been awarded a Gold Medal at the Exposition in Edinburgh, Scotland, of 1886; the Highest Medal at the American Institute, for 1882, '84, '85, and '86; also Silver Medal at Boston, 1887.



The Same Fan and Sprague's Electric Motor Combination.



For use in the Arts, for Drying, Disk Fans have made a great change. For removing Steam, Vapors, Smoke, Heat, Gases, Dust, Acids, Ammonia, etc., from rooms or buildings, they do wonderful work, and soon pay cost of fitting up and running, as the employés can do more and better work when the air of the room is in a good sanitary condition.

THE SIMONDS MANUFACTURING CO., 50 CLIFF STREET,
NEW YORK.

ACTION OF A CENTRIFUGAL FAN.

In these fans motion is not communicated to the air by impact, but principally by centrifugal force, which causes the air between the vanes of the revolving wheel to be thrown to the periphery, where it is confined by the casing, and obliged to move in a regular geometric spiral until it is released at the opening of the duct which delivers air tangentially to the wheel. The same principle has numerous other applications, as, for example, the centrifugal pump for discharging liquids, the centrifugal wringer for expelling moisture from cloth, etc.

As the air is exhausted from the centre of the wheel, more enters through the circular openings on either side of the axle; thus pressure is constantly generated between each blade and between the wheel and the casing, which serves as a spring to create motion.

As the air acquires velocity on leaving the wheel, this pressure diminishes to a point a little beyond the mouth of the outlet where the air has its maximum velocity. Were the delivery perfectly free, there would be no pressure here additional to that of the atmosphere; but, owing to the viscosity of the air and its constant displacement, there is always some resistance against which the wheel has to deliver. This is very small, however, with *low velocities*, where the air is not confined at the discharge, or is "free," and is generally omitted in estimating the "work." Where the air is at all obstructed, either by a curtain or by passing through ducts, there is a *back pressure*.

If the mouth of the outlet is small, the velocity is increased. This is the condition in the fans used as blowers to create draught through small nozzles or "tuyers" inserted in the burning fuel; here the amount of air delivered may be relatively small, and the principal work of the fan is against pressure.

In the case of ventilating fans the outlet should be large, thus insuring a large volume of air at a low velocity, the work of the fan being to overcome the inertia of a weight of air, and its secondary load the resistance of the passages and ducts.

* HEATING AND VENTILATION OF THE MASS. INSTITUTE OF TECHNOLOGY.

Centrifugal cone fan, a modification of the Sturtevant type, 12 feet in diameter, 4 feet in depth; spider has 12 arms, floats 40 inches at base, 20 inches in front. Diameter of fan mouth or inlet is 9 feet.

Fan is unhoused, the air passes through its open periphery, the cone facilitating the change in the direction of air. Area of flue openings, 63 square feet. Area of periphery discharge, 144 square feet. At 90 revolutions, and 15 indicated horse-power, 85,000 cubic feet of air were discharged per minute, = 6,375 pounds *weight of air discharged per minute*. *Work, foot-pounds per second*, 106 ÷ 64.2 x 22 = 800, *or* 1.5 *horse-power work putting the air in motion.*

Work per second *against pressure* of $\frac{1}{8}$ inch = 5.2 x $\frac{1}{8}$ = 65 pounds per square foot x 144 = 94 pounds x 11 ÷ 550 = 2 horse-power + 1.5 horse-power, or a total of 3.5 actual power, or 23 *per cent of the indicated* 15 *horse-power.*

* Prof. S. H. Woodbridge.

TABLE No. 35½.

PROPORTIONS OF CONE VENTILATING WHEELS AND POWER REQUIRED.

By ROBERT BRIGGS, C. E.

Diameter of Fans. †	Revolutions per Minute. ††	Quantity of Air delivered per Minute, corresponding to Number of Revolutions and Pressure. *	Horse Power required to deliver the quantity of Air at given pressure.	Dimensions of Pulleys. **					Proper Sectional Area of Delivery Air Duct, or Passage. ***
				Number of Pulleys.	Diameter of Pulleys.		Width of Belt demanded.		
Ft.	Number.	††† Cubic Feet. ††††	H. P.	No.	Ft.	In.	Ft.	In.	Sq. Ft. dec.
16	62½ to 125	102,500 to 205,000	7½ to 59	2	8	4	1	3	160.8
14	70 " 140	80,000 " 160,000	5¾ " 46	2	7	6	0	10	113.2
12	83 " 167	57,500 " 115,000	4⅛ " 33	2	6	9	0	8	90.5
10	100 " 200	40,000 " 80,000	2⅞ " 23	2	5	2	0	6	62.8
8	125 " 250	25,500 " 51,000	1⅞ " 14¾	1	4	0	0	8	40.2
7	140 " 280	20,000 " 40,000	1½ " 11½	1	3	6	0	6	28.3
6	167 " 334	14,400 " 28,800	1 " 8¼	1	2	8	0	5	22.6
5	200 " 400	10,000 " 20,000	¾ " 5¾	1	1	10	0	5	15.7
4	250 " 500	6,400 " 12,800	½ " 3¾	1	1	4	0	4	10.05

* Double the quantity of air will be delivered each minute if the resistance to discharge or suction is brought down to one half the pressure given in the pressure column, and the pressures may be increased (the number of the revolutions of the fans remaining constant), by closing partly the inlet or outlet, the quantity of air delivered being gradually diminished until the inlet or outlet be entirely shut off, when the pressures will have risen to double those stated in the table.

** The dimensions of pulleys and belt refer to the largest capacity of the fans given in the table, it being supposed that it may be desirable to range from the lowest quantity and pressure to the highest in each case.

*** The sectional area of the inlet or suction air-duct or passage should exceed the area given by 1.4 time, to allow a fan to produce its fullest effect. It has been found, when it was inconvenient to make the air-ducts or channels of full sectional area to the end of a system of distribution, by enlarging them 0.0025 per foot of length, so that outlets and channels, at the distance of 400 feet, were provided with double sectional areas, that the falling off of pressure was satisfactorily compensated for, at the more distant outlet. It is obvious this rule will not apply to very small air passages.

When the relationship of quantity and pressure corresponds to that given in the table, and it is never expected that a larger quantity will be required at a reduced pressure, the sectional area of the delivery air-duct may be reduced one-half, or nearly to that extent. The sectional area given, admits the passage of double the quantity of air at one half the pressure. The frictional resistances of the sides of a duct are so considerable, that the largest duct possible should always be used, even when somewhat in excess of the dimensions given as those desired.

† Doubling the diameter quadruples the discharge and the power.

†† Doubling the velocity requires seven times the power.

††† Pressure water column, 0.31 inches. †††† 1.23 inches.

TABLE No. 36.

[*]PROPORTIONS AND POWER FOR CENTRIFUGAL FANS.

Diameter of Fan in feet.	Size of Exit Opening in feet.			Velocity 5 feet per second.		Power required.	Velocity 10 feet per second.		Power required.
	Width.	Length.	Area.	Revolutions per minute.	Cubic feet of air per minute.	Foot pounds per minute.	Revolutions per minute.	Cubic feet of air per minute.	Foot pounds per minute.
3	1.5	1.8	2.7	73	810	96	146	1,620	384
4	2.0	2.4	4.8	54	1,440	171	108	2,880	684
5	2.5	3.0	7.5	44	2,250	267	88	4,500	1,068
6	3.0	3.6	10.8	37	3,240	385	74	6,480	1,540
7	3.5	4.2	14.7	32	4,410	524	64	8,820	2,096
8	4.0	4.8	19.2	28	5,760	685	56	11,520	2,740
9	4.5	5.4	24.3	25	7,290	867	50	14,580	3,468
10	5.0	6.0	30.0	22	9,000	1,070	44	18,000	4,280
12	6.0	7.2	43.2	18	12,960	1,540	36	25,920	6,160
15	7.5	9.0	67.5	15	20,250	2,403	30	40,500	9,610

The power which such a fan will require to drive it depends very much on the velocity of the current of the air issuing from it; in fact, *the power is directly as the square of the velocity, omitting the consideration of the friction of the machine*, so that velocities in the ratio 1, 2, 3, etc., require powers in the ratio 1, 4, 9, etc. There is a practical limit, however, to the extent to which power may be reduced by reducing the speed; for at very low velocities the current is apt to be retarded, or even overpowered and reversed by adverse winds.

It is known that the velocity actually realized in practice is considerably less than that due to the actuating force, the ratio varying with the lengths of the passages and the number of successive enlargements and contractions; on the large scale we may admit the ratio of .423 for the velocity, and $.423^2$ or .179 for the power required to drive the fan. Thus, say we required such a volume of air that the actual velocity through the passages must be 10 feet per second, and the theoretical power for that velocity was one horse; then the speed of the fan must be calculated for $10 \div .423 = 24$ feet per second, and the power of the engine will be $1 \div .423^2 = 5.6$ horses. But for most cases we may admit the ratio of the real to the theoretical velocity to be half or .5, and the power to be $.5^2 = .25$; admitting this, and assuming 5 feet per second as a good real velocity, we must calculate $5 \div .5 = 10$ feet per second in determining the revolutions of the fan and the power required to drive it, the real velocity of discharge being only 5 feet per second. Then with a velocity of 5 feet per second, or 300 feet per minute, the fan, having an exit opening of 7.5 square feet, would discharge $7.5 \times 300 = 2{,}250$ cubic feet per minute, or $.0761 \times 2{,}250 = 171$ pounds of air. The head due to 10 feet velocity by the laws of falling bodies is $(10 \div 8)^2 = 1.56$ foot, and the mechanical work to be done is to raise 171 pounds of air 1.56 feet high per minute, or $171 \times 1.56 = 267$ foot pounds.

The above table has been calculated this way. The centre of effort of a fan is about seven eighths of the extreme diameter, or, in our case, $5 \times 7 \div 8 = 4.35$ feet, the circumference of which is $4.35 \times 3.14 = 13.7$ feet, and for 10 feet per second, or 600 feet per minute, we shall require $600 \div 13.7 = 44$ revolutions per minute.

In cases where economy of power is not a matter of primary importance, a greater velocity may be permitted; thus, with a double velocity, or 10 feet per second, of course a double volume of air will be discharged, and the power quadrupled, becoming $267 \times 4 = 1{,}068$ foot pounds. With a 5-foot fan discharging air with velocities of 5, 10, 15, and 20 feet per second, we require 44, 88, 132, and 176 revolutions per minute, and power equal to 267, 1,068, 2,403, and 4,272 *foot pounds* respectively.

NOTE.— *The above is theoretical; practically, the power is 100 per cent greater. See page* 557.

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[*] Treatise on Heat, Thos. Box, London, 1880.

TABLE No. 37.

Experiments to determine the Relative Efficiency of Fans Discharging Air through different Apertures and at different Speeds, the Power obtained by a Weight driving the Counter-Shaft and Fan, the Discharge of Air being the Work done.

	Area of Discharge. Sq. Ft.	Weight less ⅛ for Friction of Pulleys. Lbs.	Distance Fallen by Weight Feet per Minute.	No. of Revolutions of Fan per Minute.	Velocity of Air, Ft. per Minute.	Velocity of Air in Feet per Second = E ÷ 60	Cubic Feet of Air per Minute = A X E.	Pounds of Air per Minute = G X .0747.	Ft. lbs. per Minute Power = B X C.	Ft. lb. per Minute, Effect Moving Air = F² ÷ 64 X H.	Pressure in Inches of Water. F² X .000224	Percentage of Power Utilized = J ÷ I X 100.
	A	B	C	D	E	F	G	H	I	J	K	L
1. Mills's Centrifugal Wheel with Open Periphery. Size of wheel, 2′ diameter; width, 13½″. Exhaust, ...	1.84 1.84 1.84 1.84 1.84 Inlet.	169 168 168 168 168	ft. 4-4 in. 4-3 4-4 4-5 4-5	229 229 229 245 245	670 735 676 727 761							
	1.84	**168**	**4-4**	**235**	**714**	**12**	**1314**	**98**	**728**	**221**	**.033**	**30**
Disc Wheel or Air Propeller, Free Discharge. Size of wheel, 2′ diameter—452 square inches, ...	3.14 3.14 3.14 3.14 Inlet.	168 168 168 168	6-4 6-7 6-2 6-2	336 347 347 347	As listed for 340 Revolutions.							
	3.14	**168**	**6-4**	**344**	**631**	**10.5**	**1979**	**148**	**1064**	**250**	**.024**	**23**
2. Mills's Centrifugal Wheel, Scrolled Casing,	2.30 2.30	115 115	3-5 3-6	213 213	553 560							
	2.30	**115**	**3-5**	**213**	**557**	**9.3**	**1281**	**96**	**392**	**130**	**.019**	**33**
Disc Wheel, Free Discharge, ...	3.14 3.14	115 115	5-4	283	As listed for 280 rev.							
	3.14	**115**	**5-4**	**283**	**497**	**8.3**	**1561**	**117**	**613**	**126**	**.015**	**21**
3. Mills's Centrifugal Wheel, Outlet Full Size,	2.47 2.47	88 88	3-1 2-11	171 171	445 435							
	2.47	**88**	**3-0**	**171**	**440**	**7.3**	**1086**	**81**	**264**	**67**	**.012**	**25**
Disc Wheel, Conical Discharge Pipe 4 inches long; diameter, 22.4″, ...	2.47 2.47	88 88	4-2 4-2	229 213	490 450							
	2.47	**88**	**4-2**	**219**	**470**	**7.8**	**1161**	**88**	**367**	**84**	**.014**	**23**
4. Mills's Centrifugal Wheel, Outlet Reduced 11.8″ X 13¼″, ...	1.07 1.07 1.07	168 168 168	3-11 4-2 4-1	213 213 213	965 1130 1187							
	1.07	**168**	**4-1**	**213**	**1094**	**18.2**	**1170**	**88**	**686**	**450**	**.075**	**65**
Disc Wheel, Conical Discharge, Outlet Reduced, ...	1.07 1.07	168 168	5-9 5-6	320 320	715 630							
	1.07	**168**	**5-7**	**320**	**672**	**11.2**	**719**	**54**	**938**	**105**	**.031**	**11**
5. Mills's Centrifugal Wheel, Outlet Reduced,	1.07 1.07	115 115	3-3	203	805							
	1.07	**115**	**3-3**	**203**	**805**	**13.4**	**861**	**64**	**374**	**180**	**.041**	**48**
Disc Wheel, Conical Discharge, Outlet Reduced to 14 inches diameter, . .	1.07 1.07	115 115	4-6 4-6	245 245	508 480							
	1.07	**115**	**4-6**	**245**	**494**	**8.2**	**529**	**40**	**517**	**42**	**.015**	**8**

The author's study and experiments on fan wheels and motors commenced, as seen by Table No. 37, in 1881, and were continued from time to time until satisfactory results were reached.

The primary object in view was the discovery and adoption of a method of moving air for the ventilation of schools and churches not dependent on gravity, or the natural conditions of temperature.

The matter involves, as seen, two separate studies — one that of motors for supplying the power required, and another into the kind of machine to be driven, the rotation of which should result in a large volume of air, and at the least possible expenditure of power.

After much inquiry and examination into the existing machines or fans for moving air, the writer did not find any one upon the market that seemed to meet the requirements of this distinctive and difficult class of work.

To arrive at some practical and definite information, a centrifugal fan was constructed on the lines laid down by Thomas Box, and gradually altered as experiment showed improvement in one direction or another. Some of these experiments are seen in table No. 37, page 559.

In order to see exactly what was required to drive the fan, a pulley and weight was brought to bear, by turning the fan shaft into a windlass and winding the running cord from the sheaves around it. The upper block was suspended in a high tower, and weight was added to the lower block, which, falling through thirty or forty feet, gave motion to the fan and time to observe the results.

The distance fallen by the weight was read on a vertical scale of about thirty feet in height. The number of revolutions of the large driving wheel were counted; and this, multiplied by the ratio of the diameters of the two wheels, gave the number of revolutions of the fan (column D). The velocity of the air discharged from the fan was taken by an anemometer directly in front of the fan at the discharge opening, the position of the instrument being varied so as to secure an average velocity. From these data the work of the power applied (column I) and the work recovered in moving the air (column J) were determined, and the percentage of power utilized (column I), which shows the comparative efficiency of the two fans for the several conditions.

Later, the water pipe was brought into the experiments, and small motors run by the hydrant pressure were put to raising the same weight, which had before driven the fan, until finally the motors were belted directly to the fan shaft. We now had a falling weight and one that did not require returning to the height from which it had fallen, and were able to determine both the weight of the water, and the weight of the air that was put in motion. The substance of these experiments was condensed, and is seen in the following table, No. 38.

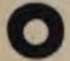
TABLE No. 38.

EXPERIMENTS WITH AIR, FOR PURPOSES OF VENTILATION, AT GRAND RAPIDS, MICH., 1881.

Air Moved by Mills's Fan, Actuated by Water Motor, and Hydrant Pressure 17 to 45 lbs.

Fan Diameter 3 Feet, Width 19 Inches, Inlet and Discharge Openings 3 Square Feet.

See also Diagram 34, page 585.	Pressure per square inch. LBS.	Motor, revolutions per minute.	Water, gallons per hour.	Cost at 10 cents per 1,000 gallons. Cts.	Fan, revolutions per minute.	Air, velocity per second.	Air, velocity per minute.	Air, cubic feet per minute.	Air, cubic feet per hour.	Air, pounds per minute, $H \div 12.5$	WORK. Foot-Pounds per Minute. (Effect) (Air) $J \div 64 \times F^2$	Power, (Water). $32 \times A \times C$	Efficiency, Foot-pounds per gallon, $= L \div C$	Cost of Moving 100,000 cub. ft. Air. BACKUS. Diam 11″ Av. rev., 589.	TUERK. Diam. 6″ Av rev., 1,383.
Backus Motor. 11″ Diameter.	17	396	120	1.2	72	7½	450	1350	81,000	108	95	653	47.5	Cts. 1.5	ct.
	20	412	131	1.3	75	8	480	1440	86,400	115	115	838	53.	1.5	1.5
	25	522	146	1.5	95	9⅞	594	1782	106,920	143	206	1,168	87.	1.4	1.3
	30	605	165	1.6	110	11½	687	2061	123,660	165	331	1,584	128.	1.3	1.2
	35	660	176	1.8	120	12½	750	2250	135,000	180	427	1,971	146.	1.3	1.2
	40	726	195	1.9	132	13¾	825	2475	148,500	198	576	2,496	177.	1.3	1.2
	45	803	206	2.1	146	15	912	2736	164,160	218	763	2,966	221.	1.3	1.3


= Actual Size of Jet Delivery of Water to the Motors.

Average, 766 cu. ft. of Air (Velocity, 720 ft. per min.) moved per Gallon of Water. Average pressure, 31 lbs.

See also Diagram 34, page 585.	Pressure per square inch. LBS.	Motor, revolutions per minute.	Water, gallons per hour.	Cost at 10 cents per 1,000 gallons. Cts.	Fan, revolutions per minute.	Air, velocity per second.	Air, velocity per minute.	Air, cubic feet per minute.	Air, cubic feet per hour.	Air, pounds per minute, $H \div 12.5$	WORK. Foot-Pounds per Minute. (Effect) (Air) $J \div 64 \times F^2$	Power, (Water). $32 \times A \times C$	Efficiency, Foot-pounds per gallon, $= L \div C$
Tuerk Motor. 6″ Diameter.	20	952	120	1.2	75	8	480	1440	86,400	115	115	768	57.5
	25	1120	135	1.3	90	9	562	1686	101,160	135	170	1,080	75.5
	30	1288	143	1.4	102	10⅝	637	1911	114,660	153	271	1,373	114.
	35	1456	158	1.6	117	12	731	2193	131,580	176	396	1,770	151.
	40	1638	173	1.7	127	13	793	2379	142,740	190	502	2,214	171.
	45	1844	191	1.9	134	14	837	2511	150,660	201	615	2,750	193.

WATER.

1 cubic foot weighs 62.5 pounds = 7.48 gallons.

1 gallon weighs 8.36 pounds and contains 231

DESCRIPTION OF THE MILLS FAN.

The objective points sought in this wheel were:—

1. A large volume of air with the least possible power.
2. *Lightness, strength, and low cost of construction, and that it should be perfectly noiseless in operation, and require little attention.*

As before stated, investigation showed that, to move a large volume of such a yielding and unstable substance as air, there must be a *large area of blade, moved at a comparatively slow velocity, to avoid slippage and loss from the air taking other directions from the one sought.*

The reasons that determined that the fan should be "centrifugal," rather than "radial," in its construction and action have already been foreshadowed in our remarks on the disk and cone wheels.

By examination of the following figures, elevation and sectional plan, it will be seen that this is a fan wheel of the centrifugal type, of large diameter and great width, the proportions being, diameter twice the width, with two inlet openings of three feet each, and a discharge opening of from twelve to fourteen square feet — equal to a pipe four and a half feet in diameter.

The shaft passes through the case at right angles; from this proceed the arms carrying the ribs, to which are secured the blades. These blades are of light sheet metal, curved on a true circle, with a radius of three eighths the diameter, struck from a circle of about one third the diameter, which gives inlets to blades of eight inches, gradually increasing to the outlet. A blade is thus secured *three feet wide by four feet long, equaling twelve square feet,* and of expanding pitch from the heel or inlet to the periphery, so that the air is gradually put in motion and discharged with a velocity equal to three fourths that of the extremities of the blades.

The noticeable fact about this fan is that the blades travel mainly in the line of the current of air instead of across or at an angle with it, the heel of the blade (at a distance from the dead centre of eighteen to twenty inches) has a certain value, constantly increased as a further distance is reached towards the periphery: thus there is no slippage or tendency towards it, even when compressing the air at the discharge outlet. This is shown in the preceding table, No. 38.

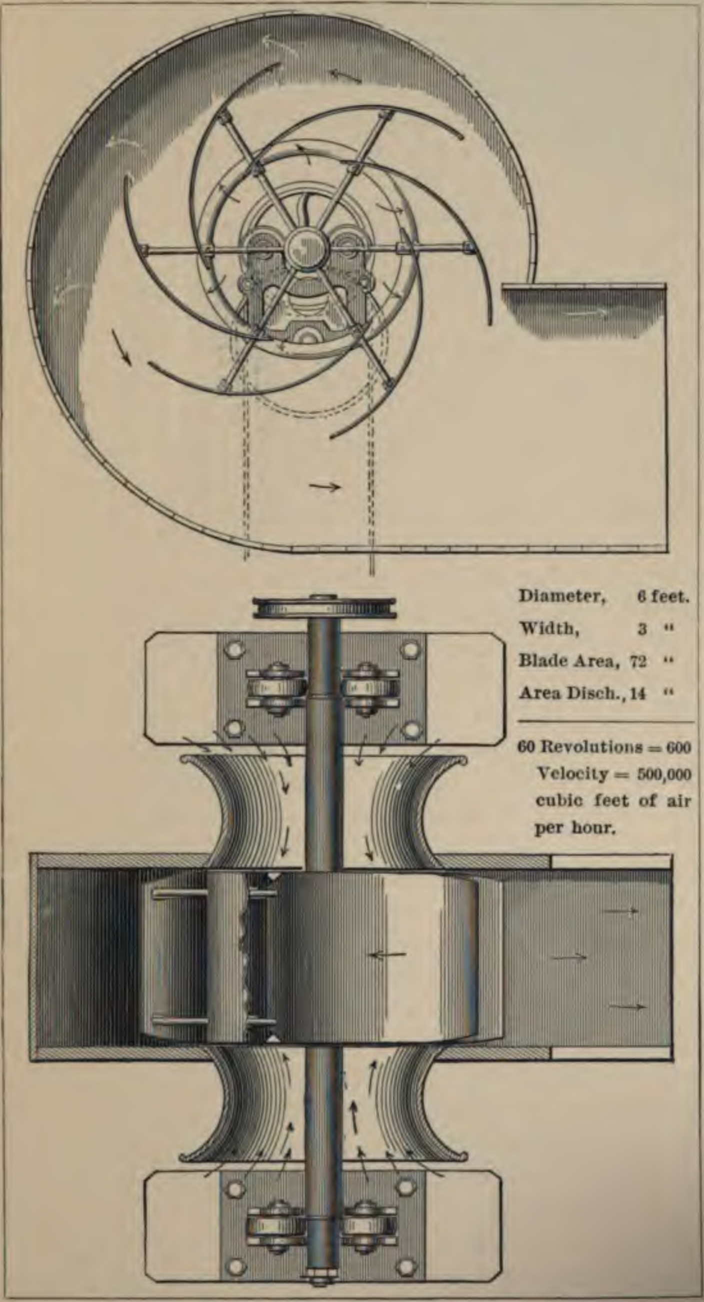
The hoods or chambers surrounding the inlets to the wheel operate to cut off the side currents producing a "veni contractor," which diminishes the flow of liquids through an opening in a thin plate. The roller bearings are not required except in the largest sizes — seven to ten feet.

The smaller sizes will be mounted on cone centres the same as lathes, further reducing the friction, and dispensing with oil for the bearings. For general proportions and power required, see page 558.

PLATE No. 49.

MILLS' FANS, ELEVATION, AND SECTION THROUGH CENTRE.

These are the Fans referred to as employed at the Buffalo, N. Y., Insane Asylum and School Buildings, Nos. 10 and 13 also at County and other buildings, at Springfield, Mass., and at Trinity Church, Copley Square, Boston, Mass., 1887.



Diameter, 6 feet.
Width, 3 "
Blade Area, 72 "
Area Disch., 14 "

60 Revolutions = 600 Velocity = 500,000 cubic feet of air per hour.

For Power to Operate, see Certificate of COST OF WATER FOR THREE MONTHS (Page 589), Court House, Springfield, Mass.

Also Table No. 39, Cost of Ventilation by Other Methods.

Plan showing Shaft, Blades, Hood around Inlet, and Roller Bearings used larger sizes. See also Table No. 38, Exp'ts on Centrif. and Disc Whe

SOME APPLICATIONS OF THE MILLS SYSTEM OF VENTILATION BY FAN AND HYDRAULIC POWER.

The experiments to determine the conditions surrounding the heating and ventilation of school buildings were made, as seen by table No. 37, in the year 1881; but they were not carried into practical effect until the writer removed to Buffalo, N. Y., in 1883, 1884, the first fan being put into school No. 13. For description of this apparatus, see report of Commissioners, pages 400 and 568.

The next application of these machines and methods was to the six isolated buildings of the Buffalo State Insane Asylum, in 1884, 1885. For schedule and report of the Commissioners, see pages 118, 119; also pages 449 and 450. A little later, or in 1886, school No. 10 was warmed by a water circulation, the air being mechanically exhausted by the Mills fans. For report on this building, see letter of Professor Fish, page 523, also that of Architect Wm. B. Allen, page 567.

In 1886 these wheels were put into the Court House at Springfield, Mass. It was at this city that the combined water-heating and ventilating apparatus was employed in the county buildings, 1888. For full description of this plant, see Chapter XXIV. and letter of the Commissioners, pages 448–50. There was another fan and system of water heating put into the Bay Street School at Springfield by the Phillips Manufacturing Co. See report of the inspectors, table No. 24.

A further use of this system of ventilation was in the reheating of Trinity Church, Boston, Mass., 1888, Rev. Phillips Brooks, rector. Description of this fine church and the arrangements for heating will be found on page 451. A duplicate of this apparatus was also put into the new Eliot Congregational Church at Newton, Mass., 1889. The contractor for this work was Albert B. Franklin, Boston, who later adopted the system for the new and old college buildings on College Hill, at Worcester, Mass. There have also been several other applications of this ventilating apparatus. One is just being completed in the new City Hall at Haverhill, Mass. See page 566.

Churches and schools are not favorably circumstanced, as regards the employment of mechanical ventilating wheels, if such wheels must be driven by steam power; since steam at any considerable pressure is undesirable, and should be ruled out of the available mediums for either heat or power. This is now generally understood, owing to the poor and unintelligent janitor service usually employed in these buildings. Of six applications of steam-driven ventilating disk wheels in Boston school buildings, at least four of them have been discontinued, while the other two are operated at a great disadvantage, and under protest from the principals and Supt. of Public Buildings. See annual report 1890 of Inspector of Hygiene, Dr. John B. Moran.

HEATING AND VENTILATING OF THE BUFFALO INSANE ASYLUM.

The first apparatus constructed and finished with the building, 1881, was not satisfactory, either in heat or ventilation, requiring 25 pounds of steam for circulation, was noisy, and gave constant trouble; water of condensation did not return to the boiler-room but to hot well, 14 feet below boiler-room floor.

The ventilation on the plenum system was a failure. One half of all the air put in motion by a 12-foot fan and large steam engine was lost before reaching the buildings, three of which received no air from this source. The stoppage of the engine at night deprived the buildings of even the small day supply.

The Nason ventilating fan wheel was 12 feet in diameter by 5 feet wide; inlet opening, 28.25 x 2 = 56.50 square feet; revolutions per minute, 100; air discharged, *by theory*, 140,000 cubic feet; per hour, 8,400,000; and the horse-power (13), required to put this air in motion cost (4 pounds of coal per hour per horse-power), 4 x 13 = 52 pounds per hour, or 624 pounds of coal per day; at $5 per ton, $1.56 per day; cost of attendance, oil, etc., $1.50 per day.

By experiment the air per minute was only 66,000 cubic feet delivered at the outlet from the fan; x 60 = 3,960,000 cubic feet per hour. At a distance of about 400 feet, or previous to the first use of the air, only 3,000,000 cubic feet per hour was found, or a loss of 25 per cent.

The demand for the central building, wards A and B, is about 1,200,000 cubic feet per hour; and the final 3,000,000 cubic feet only avails for this demand.

Thus only about 30 per cent of all the air started from the fan was utilized, and the cost of each 100,000 cubic feet of air actually delivered in these buildings is double what it should be.

* At the reconstruction of the apparatus, 1885, by the writer, 14,000 square feet of radiating surface *was removed*, the piping changed, and the pressure reduced. The ventilation was also changed from the *plenum* to the *exhaust* system, each building having its own fan driven by a water motor. Later these were changed to steam engines.

Briefly, the general features of the ventilating apparatus and the results may be stated as follows: Each building has its own fan and motor, which are under perfect control by means of a single valve in the basement, and capable of driving the fans from 50 to 70 revolutions per minute, as more or less water is used. At 50 revolutions of the fans, 6 feet in diameter, a velocity of 500 feet per minute is given the air at the discharge openings, which are from 10 to 20 square feet, as the size of the building requires.

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* See report of the Commissioners, pages 118, 119.

SOME LATE EXAMPLES OF VENTILATION.

*"ELIOT CHURCH, NEWTON.— This building, recently constructed, is one of the finest structures of its kind in the State. The introduction of fresh air is amply provided for, also means to remove the vitiated air therefrom. The cubical contents of the large audience room is 502,250 feet. The vestibule and side room have 26,531 cubic feet in addition. The introduction of fresh air is very uniform in its character. The entire structure is heated by two of Mills' patent water-heating sectional boilers, each equal to 30 horse-power. Under the main audience room are 6 large air chambers, in which are stacks of Gold's pin radiators, equal to 2,400 feet of surface for heating air that enters the church; not including the vestry, which is provided in a similar manner with hot-air chambers. For these chambers, above described, are 16 openings through the floor to the main audience room, with registers 14 x 18 inches. In addition to the indirect heat there are 2,600 square feet of surface in vertical radiators, arranged under the windows and near the several entrances, to counteract the cold currents coming from that direction.

"The vitiated air is removed from the room through 8 registers in the floor, 10 by 36 inches, and two 30 by 30 inches. These openings are connected under the floor, by graduated metal pipes of galvanized iron, to two 42-inch pipes; and through these pipes the air is exhausted from the church by the use of a Mills fan, to which the 42-inch pipes are connected. The fan is operated in the basement by a Tuerk water motor, with a pressure of 80 pounds to the square inch. *Using but two cubic feet of water, it removes 10,000 cubic feet of air per minute.* From the fan the air is delivered into 2 perpendicular shafts, each having an area of 17 square feet; these intersect in the attic, forming a single flue, and thus passing out through the roof. In the ceiling over the gas chandelier are 10 open registers, 5 feet in diameter. All the air vitiated by the burning of the gas passes into the attic, thence, at a rapid velocity, out of the attic chamber through an opening into the large central flue.

"The fan is hindered in its operation, on account of working against pressure. For some unknown reason the connecting flue of brick between the fan and the main shaft is so contracted in its construction as to give the opening an area of but 13 square feet, while the fan is exhausting from an opening of 19 feet, and moving but 600,000 cubic feet of air per hour, *when its capacity, with 80 revolutions per minute, is 900,000 but for this error in the construction of the discharge flues.*"

The contractor for this work was Albert B. Franklin, of Boston, Mass.

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* Report of Chief of District Police Rufus R. Wade, 1890.

*THE FIFTH AVENUE PRESBYTERIAN CHURCH, NEW YORK CITY.

"This church covers an area of 100 by 200 feet, and the auditorium is 100 feet deep on the main floor, 136 feet deep in the gallery, 85 feet wide, with a ceiling 60 feet high, and is intended to furnish comfortable seats for 2,000 persons. At the northwest corner of the building is a tower 100 feet high and 16 feet square, which serves as a fresh-air shaft, down which the air is drawn by a fan at the base of the tower. The entire basement of the church is a fresh-air chamber, on the ceiling of which is a network of steam-heating pipes, 2 inches in diameter, amounting altogether to 9,000 feet in length. There is also an auxiliary coil in the air chamber containing 4,410 feet of 1-inch pipe, which is divided into 4 separate steam coils, each of which can be used independently. This auxiliary coil is in itself nearly or quite sufficient to furnish all the heat required under ordinary circumstances. But the pipes beneath the floor have been found very useful in warming the floor of the pews. The basement extends under the entire building, and is about 9 feet in height.

"It is not ceiled nor plastered. The warm air forced by the fan into this basement air chamber, passes into the body of the church through openings in the risers of the stationary foot-benches of every pew, these openings being controlled by slats or registers, in such a way that the occupant of each pew can regulate the inflow of air at his pleasure. The air also escapes into the aisles through openings in the ends of the pews.

"Steam is usually turned into the pipes underneath the floor about twenty-four hours before the service in winter, and is turned off when the audience begin to enter when the fan is put in motion.

"The forcing in of fresh air by the fan is continued between the interval of the morning and afternoon services, thus thoroughly flushing out the church. In warm weather the air is cooled by the spray of water from a perforated pipe at the bottom of the fresh-air shaft, and by the use of ice the temperature of the incoming air has been lowered as much as 6°.

"The fan is similar to that used in the Capitol at Washington, is 7 feet in diameter of disk, 8 5/16 inches wide at the tips of the blades, 5 feet in diameter at the mouth, 15 inches width of blades at the mouth, having ¼ of an inch clearance between the edges of the blades and the wall or fan side, with an area of 19 square feet at the mouth, and 15 square feet at the periphery. The area of the duct or passage leading from the chamber is 20¼ square feet."

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* Mr. Carl Pefeffer, *Architect.*

EXTRACTS FROM BUFFALO EXPRESS AND TIMES, 1883, 1884.

At half-past two o'clock yesterday afternoon a company composed of Messrs. John Kenyon, City Hall Engineer, Dr. J. W. Keene, District Physician, Dr. William C. Phelps, Health Physician, Comptroller Mahoney, Alderman Patridge, and City Engineer Rogers made an inspection of the new apparatus employed in heating and ventilating School No. 13, on Oak Street. The entire machinery was inspected from the new safety-boiler, fan, and pipes, in the basement, to the cold and hot air flues, in the three stories and adjoining recitation and cloak rooms. The improvements were made from plans and specifications drawn by Mr. John H. Mills, at a cost of $4,000. The contracts were let to different parties for the execution of the different departments of work, and were performed under the general superintendence of Mr. Mills. The chief result accomplished was the transformation of the basement from a wet, dark, and malarial hole into a dry, light, and wholesome apartment, in which were placed the heating apparatus, fuel, closets, etc. To effect this, drains were laid beneath a new floor, from the rear of the building to the street. Hopper closets, twenty-one in number, were put in the two rear rooms of the basement. The main closets are ventilated by two galvanized iron shafts extending through the roof and enclosing steam pipes to ensure the active movement of the air. The heat for the building is furnished by a Mills safety sectional boiler, and is delivered to *direct* radiators under the windows (to heat the air which leaks in) and to the *indirect* heat chamber, through which all the air passes on its way to the rooms. Pure air is provided by means of a shaft *descending from the roof to the basement*, where a large fan-wheel creates a current and keeps the air in motion through the indirect-radiator-ducts, and registers to each room. Ample provision is made by flues in the outer walls to remove the vitiated air. A current of warm, pure air is thus constantly passing through the rooms, the amount of which is equal to a supply of over nine hundred cubic feet per hour to each pupil. This was ascertained by actual measurements with the anemometer. The fan which creates the current is of peculiar construction, and is operated by a water motor, using a jet of water only one fourth of an inch in diameter, with a pressure of but twenty-two pounds. *The water discharged from the motor is then conducted to the urinals. There is thus no more water used than would be required without the fan, while a more efficient ventilation is secured.*

In taking the steam over the building for the direct radiator, the *Mills overhead* system was employed. By this means the steam is first passed to the upper story and supplied to the radiators on its *return to the boiler*. This new and efficient system is being largely introduced. It is in use in the Young Men's Association building, including St. James Hall, several fine stores, and the new Police building on the Terrace.—*Buffalo Morning Express*, 1883.

From the *Times*, Buffalo, May 9, 1884:—

Alderman Parsons, from the Special Committee on the Examination of the Several Public Schools, offered the following report, and moved that it be referred to the Committee on Schools:—

"In conclusion, we wish to call the attention of your honorable body to the vital importance of improving the ventilation in many of the school buildings; for on this, more than anything else, depends the health of the pupils and teachers. We caused to be made in two school buildings an analysis of the air, and found that in *No.* 13, *which is the best ventilated school building in the city*, there was less than *four cubic inches* of carbonic acid in *eleven thousand* cubic inches of air; while in No. 15 primary, which is a fair sample in regard to ventilation in most of the school buildings, *twenty cubic inches* of carbonic acid was found in *eleven thousand cubic inches* of air. These tests were carefully made during school hours. The test in No. 13 shows what can be done to improve ventilation, while the test in No. 15 primary shows the necessity of a proper system of ventilation in all the public schools."

W. P. BURNS, *City Clerk.*

OFFICE OF WM. B. ALLAN,
Architect and Superintendent.

ST. CATHERINE'S, ONT., March 10, 1887.

J. H. MILLS, ESQ., Constructing Engineer, Buffalo, N. Y.

Dear Sir: I learned, when last in Buffalo, that you had in contemplation a book relating to the principles involved in the proper warming and ventilation of buildings; and I take this method of expressing my personal satisfaction that such is the case, and to assure you of the appreciation that your work will meet from the architects of the Provinces, who, having perhaps less opportunity to see the improvements which are always in progress in the States, are quite as ambitious to learn and profit by such practical information as you can supply.

I may remark that my first connection with your methods and machines in buildings erected by me was in the fall of 1877 and the warming and ventilation of the First Presbyterian Church, of which you have letters of approval from the trustees. Later, the warming by steam of the large cotton mill at Merriton, in which your overhead system of steam distribution played so important and successful a part.

The many dwellings here in which your boilers and radiators have been placed, using a water circulation, may be mentioned as the most successful of any yet introduced; while your own application of water heat and mechanical ventilation to the stone mansion of Thos. R. Merrit, Esq., showed that, up to that time, people in the heating business in the Provinces had little conception of the advantage and possibility latent in a properly arranged water apparatus working under pressure instead of the old open-tank system.

I have examined carefully your method of warming and ventilating several school buildings in the city of Buffalo. That in School No. 10, warmed mainly by indirect water radiators with auxiliary steam coils under the windows, ventilation being effected by exhausting the vent flues in the attic, appears to fill every demand of this line of difficult work, with a system as simple and as inexpensive as it is efficient and durable; while the same arrangements on a larger scale at the Buffalo State Insane Asylum shows that there is no limit to its application and efficiency in all classes of buildings.

Your ability to move fans of the largest diameters in buildings having no possibility of employing steam power is one of the most novel and valuable of your improvements. Ventilation seems no longer a problem, but a fact.

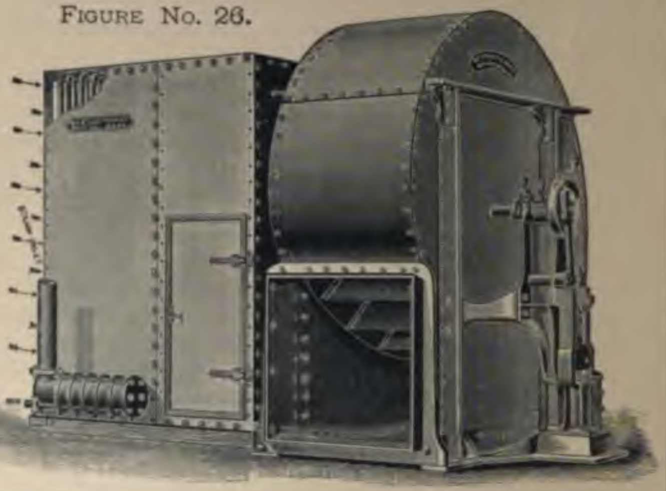
Yours Very truly
Wm B. Allan

THE STURTEVANT SYSTEM OF HEATING AND VENTILATION.

The general arrangement of the Sturtevant system of heating and ventilating is briefly as follows: The apparatus is formed by the proper combination of a fan, an engine, and a steam heater, all of special construction. The entire heating surface is then encased in a steel-plate jacket connecting with the fan.

The apparatus is usually placed in the basement, and steam is supplied by a boiler of suitable construction; the exhaust steam from the engine being also utilized in the heater. The action of apparatus is rendered automatic, by the use of automatic water-feeding and damper-regulating devices.

FIGURE No. 26.



The casing of the heater is so constructed, in connection with a double system of air-supply ducts, that cold air may be forced through one system, and hot air through the other. A hot and cold air duct communicates with the base of each of the upright flues in the walls, and dampers are so arranged that the temperature of the air admitted to any room may be instantly changed at will, without changing its quantity or in any way affecting the admission of air to any other rooms. Separate flues communicate with each room, so that it is rendered entirely independent of the remainder of the building. Air is admitted to the rooms from these flues at eight or ten feet above floor level, and finally escapes through the wall ventilating registers close to the floor, and nearly beneath the inlet registers.

The arrangement of hot and cold air ducts does away with the use of indirect steam coils at the base of each flue, with the attendant expense and inconvenience, centralizes the entire heating system in a single steam-pipe coil, in a fire-proof jacket, greatly reduces the heating surface and the number of valves, and renders the entire system capable of ready and instantaneous control, if in the hands of a practical engineer.

NOTE. — A fact connected with this method of mechanical or forced circulation of air over steam pipe or coils, is the greater amount of heat that can be taken from a given amount of heating surface.

Under natural currents the heat is limited to from 300 *to* 400 *units per square foot; this is obtained with* 150 *to* 200 *cubic feet of air per foot of surface per hour, while* 1,000 *cubic feet of air will give a return of* 900 *to* 1,300 *units.*

See diagram No. 19, page 369.

CHAPTER XXX.

MISCELLANEOUS EXAMPLES AND CONDITIONS.

THE RELATIVE ECONOMY BY FANS AND BY HEATED CHIMNEYS.*

OF the various modes of producing the air currents by which vitiated air is removed from chambers, halls, or working places, and fresh or pure air simultaneously introduced, involving the processes of ventilation, the heated chimney or flue is the most common; although it is generally recognized that, where large volumes of air are to be moved against considerable passive or frictional resistances, the use of the fan or blower is theoretically the most economical.

"In any investigation having for its object the relative economy of the methods of putting the same quantity of air in movement per second, through the same channels, and with the same velocity, it will be sufficient, therefore, to consider only the work $w\frac{v^2}{2g}$ (due to inertia), since the work performed per second in both cases, must be the same whether the frictional resistances are considered or not.

"Economy of heat requires that the *velocity* shall be kept small and the increase of *volume* obtained by enlarging the chimney and the channels or conduits through which the air passes. Moreover, since the resistances from friction diminish in rapid proportion as the channels are enlarged, and more of the total head produced by the chimney becomes available to create the velocity of flow, an additional advantage in large cross sections for the chimneys and conduits is secured. The same laws of expenditure of heat hold for the fan or blower, the expenditures of heat increasing for the same conduit as the cube of the velocity of flow.

"It often happens that by a particular chimney and channels of flow the ventilation becomes insufficient, and, instead of increasing the heat in the chimney with a large additional expenditure of fuel, a fan is introduced to take the place of chimney ventilation. The relative efficiency, with the application of this law of the proportion of heat expended to the velocity of discharge, enables us to ascertain to what limit such a substitution of a fan for a chimney may be carried before the cost of the fan exceeds the cost of the furnace ventilation.

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* Extracts from a paper by Professor W. P. Trowbridge, 1886.

"For a chimney five hundred feet high the velocity by a substituted fan could hardly be made twice that produced by the chimney, before the cost of the fan, with increased ventilation, should exceed that of the chimney. The question might then turn upon the advisability of getting the increase by additional heat in the chimney, even with a large additional expenditure of fuel; the cost of attending and maintaining the fan becoming an important element in the problem. It is quite evident that for the fan, as well as for the chimney, low velocities and large conduits are desirable.

"The heat furnished may be supplied by a furnace at the base of the chimney,— the heated products of combustion from which mingle with the air which enters the base of the chimney,— by a system of steam pipes which heat the air by contact, as it passes through or among them, or by any other mode which will accomplish the result. If a fire or furnace be employed in such a way that the dissipation or loss of heat from the furnace is prevented, the efficiency of the furnace may be considered unity.

"In ventilation by a fan or blower, driven by a steam engine, the heat expended to produce the same velocity or the same discharge and renewal of air *will depend on the efficiency of the steam boiler and engine, the efficiency of the fan or blower, and the loss by friction.*

"If the chimney be heated by steam pipes at its base, the efficiency of the boiler and pipes must be taken into consideration, making a result still more *unfavorable to the chimney.*

"The employment of steam pipes at the bases of ventilating flues seems to me to be worthy of more extended application than has heretofore been accorded to this method of promoting activity of circulation of air for the purposes of ventilation.

"Extensive use of steam coils in aspirating flues is made in the Johns Hopkins Hospital at Baltimore. In this case a certain part of the efficiency in some of the steam coils is lost, owing to the fact that they are placed high in the shafts, above the entrance into the shafts of the upper air ducts, which are the ones which will do most of the work in warm weather. This loss might have been avoided by bringing these flues down to the base of the aspirating chimney, at which point the accelerating coils might then have been placed, with the result of obtaining a longer column of heated and rarified air and a corresponding increase of power. For ordinary and the most favorable circumstances the actual velocity in the flue is best if it be established at about five feet per second, and it is for this actual velocity that the following dimensions are specified: —

"*The cross section of the flue in square feet should be three times the weight of air discharged per second.* See table No. 39, page 575.

"Suppose the air of a room 30 x 40 feet and 15 feet from floor to ceiling is to be renewed four times every hour.

"The cubic contents are 30 x 40 x 15 = 18,000 cubic feet. At the ordinary temperature and pressure the air will weigh about $\frac{8}{100}$ of a pound per cubic foot, and the weight of air discharged per hour will be 4 x 18,000 x .08 = 5,760 pounds, or 1.6 pounds per second.

"The required area of cross section will be A = 3 x 1.6 = 4.8 square feet. If now we suppose the steam in the coil to be low-pressure steam,— for instance, 5 pounds above the atmosphere,— we shall have for its temperature 228° Fahr., and, if we assume the exterior temperature of the air to be 60°, we shall have conditions which will apply to spring or autumn weather; and the same arrangements then determined will give better results in winter or cooler weather. If the flue is 50 feet high, we shall have 147 square feet.

"It may be thought that this amount of surface is excessive for the degree of ventilation assumed.

"The reply to this objection is that, if *any one expects to obtain full and sufficient ventilation without expending an appropriate amount of money both for fixtures and for fuel, such a one is mistaken. It might as well be expected to get water from a well without means for drawing and pumping it. The size of the bucket or pump and the power applied will determine the exact amount of water obtained per hour and the cost of obtaining it. The sooner this law is universally recognized for ventilation, the sooner will ventilating arrangements be generally successful.*

"Hence the conditions of ventilation assumed will require an aggregate area of heating flue of 4.8 square feet in cross section and 147 square feet of heating surface in the coil or cluster of pipes at the base.

"If more than one flue is employed, which would probably be desirable, in order to have a better distribution of the inflowing air (two flues, for instance), then each would have an area of 2.2 square feet, and each should be heated at the base by pipes having 73½ square feet of surface." See table No. 29, examples 9, 10, and 11.

One point in particular brought out by studying this system of ventilation is worthy of careful attention; namely, to ventilate a building, means that there is work to be done. The performance of work means an expenditure of force; therefore, any system professing to secure ventilation without performing work or, what is the same, without expending force, is without effect.

The ventilation of a building should be like its water supply and sewerage, always ready for work, and certain in its effects. When buildings are erecting, such a condition can be attained at moderate expense, while it may be exceedingly difficult to accomplish after the completion. It is then of the highest importance that ventilation be considered in connection with design.

EXPLANATION OF TABLE NO. 39.

This table compares the cost of different methods of ventilation, the final result for all systems, being the cost in cents and fractions of a cent *per hundred thousand cubic feet of air removed, is shown in the final column in black type at the right of the table, column N*.

The first section of the table shows the conditions where an open fireplace is used as a means of ventilation, the air from the room being drawn up the chimney in connection with other products of combustion.

In the experiments here shown, the same chimney was tested with gas (in small jets) and with wood and coal. The results are taken directly from Box, Treatise on Heat, with the exception of the estimate of the cost. It will be seen that the cost of gas greatly exceeds that of ventilation by other methods; this is with gas at $2 per M. If, instead of illuminating gas, some cheaper substitute were employed, as, for instance, natural gas at 10 cents per M, the cost would here be reduced one twentieth, or to two and three tenths cents per 100,000 cubic feet removed, where it would favorably compare with other fuels.

In section 2 a number of examples are shown from different authorities on ventilation by means of an upright shaft, with fire at the base. The first two examples show the result of observations at a large prison in Paris, both summer and winter. In this case, as also in that below of fans actuated by steam power, there will be an addition to the cost of ventilation over the fuel consumed, for attendance, repairs, etc., the amount of which is estimated separately in column M, and is added into the total.

Professor Trowbridge, of Columbia College, has fully investigated the subject of ventilation by different methods, and examples are shown in section 3 where the amount of steam-pipe surface required, is taken from his formula. Column A shows the area of the flue section required for the passage of the air, or 100,000 cubic feet per hour at the velocity (as recommended) of about 5 feet per second in the flue; this is equivalent to a velocity of 4.2 feet per second of the air when the density is that due to a temperature of 60° (column F). The temperature of the outside air is here taken at 60° (column D), and the height of the flue varying in the three examples from 50 to 30 feet (column B). The number of cubic feet of air per square foot of pipe surface per hour, obtained by dividing 100,000 by the amount of pipe surface demanded, is shown in column H, and in column I the number of units of heat that would be transmitted by the pipe to the air when passed over it at this velocity.

By comparison of columns B, E, and F in the examples illustrating ventilation by heat, it appears that a temperature in the flue of from 100° to 200° is required to secure an active and reliable discharge of the air at a velocity of from 5 to 10 feet per second.

Column J shows the coal required; and from this is readily obtained the cost per hour and per 100,000 cubic feet, the cost for attendance in this instance being the lowest of any.

In the examples of ventilation by means of fans driven by steam engines, the *power* is obtained from different authorities for disc and centrifugal fans, and from this the amount of fuel is readily estimated, the standard being 4.5 pounds of coal per horse-power per hour. It should be explained that the power required for the disc fan of the Blackman type is obtained by direct experiments made by G. A. Suter, M. E.; while for the centrifugal fan, in default of extended experiments with large fans, the power is shown as *estimated* by Thos. Box. An addition has here been made to the cost to allow for attendance, repairs, and interest on capital invested in engines and deterioration of plant.

The last section comprises instances in the author's practice of mechanical ventilation, his centrifugal fans being employed, the power obtained by water motors of the *jet* type, such as the *Tuerk*, *Cooper*, or *Backus*.

See experiments and diagram.

TABLE No. 39. The Cost of Ventilation by Heat with Different Fuels and by Mechanical Appliances.

No. for Reference.	AUTHORITIES. MORIN, PECLET, G. W. RAFTER, THOS. BOX, PROF. TROWBRIDGE, G. A. SUTER, JOHN H. MILLS. (See also Table 37 and page 589.)				TEMPERATURES.		AIR.				FUEL.		Cost per 100,000 Cubic Feet of Air moved.		
		Area of Flue Section. Square Feet.	Height of Flue in Feet.	No. of Square Feet of Pipe Surface.	Outside Air.	Air in Flue.	Velocity in Feet per Second *into Flue.*	Cubic Feet per Hour.	Cubic Feet of Air per Hour per Square Foot Pipe Surface.	Units of Heat per Hour per Square Foot of Pipe Surface.	Coal and Wood, Lbs. per Hour. Gas, Cubic Feet per Hour.	Per 100,000 Cubic Feet of Air Moved.	Coal at $5 per Ton. W'd $6 pr C'd, 3000 Lbs Gas at $2 pr 1000 Cu. Ft.	Attendance per Hour, Janitor, 20 Cents, Engineer, 25 Cents.	TOTAL COST.
		A	B	C	D	E	F	G	H	I	J	K	L	M	N
	Chimney, Open Fire Place.												Cts.	Cts.	Cts.
1	Experiments (Morin) with Gas, 106 Jets, . Thos. Box, page 274.	2.31		$=\frac{(459+D)\times G}{30\times(228-D)\times B}$	64	146	4.1	34,591		From Experiments by C. B. RICHARDS—Pipe Coil. (See Diag. No. 13, line C.)	81.8	236.0	47.0	0.	**47.0**
2	Experiments (Morin) with Wood, ...	2.31			53	205	5.6	46,498			17.8	38.3	7.7	.2	**7.9**
3	Experiments (Morin) with Coal, ...	2.31			49	207	5.1	43,181			8.6	19.9	4.4	.2	**4.6**
	Ventilating Shaft, Fire at Base.										Lbs.	Lbs.	Cts.	Cts.	Cts.
4	Ventilation of Prison Mazas, Paris, Winter, . .	33.	95		39	84	8.9	1,059,600			44.	4.2	.9	2.	**2.9**
5	Ventilation of Prison Mazas, Paris, Summer, .	33.	95				8.9	1,059,600			55.	5.2	1.1	2.	**3.1**
6	Experiments by Peclet (Box, page 260), ...	9.	33				1.3	42,400			2.2	5.2	1.1	2.	**3.1**
7	Ventilation of School-House, G. W. Rafter, . .	14.9	55		54	114	15.8	850,000			66.4	7.8	1.7	2.4	**4.1**
8	Ventilation of School-House, Thos. Box, page 259,	1.6	12		70	120	3.5	22,000			1.6	7.3	1.6	2.	**3.6**
	Ventilating Shaft, Steam Pipes at Base.								G ÷ C		$\frac{I\times C}{7{,}000}$	Lbs.	Cts.	Cts.	Cts.
9	Report of Prof. Trowbridge (*School of Mines*	6.6	50	206	60	121	4.2	100,000	486	540	15.9	15.9	3.5	0.	**3.5**
10	*Quarterly*, 1882). See pages 575, 576, 577 . .	6.6	40	258	60	129	4.2	100,000	388	487	17.9	17.9	4.1	0.	**4.1**
11		6.6	30	343	60	144	4.2	100,000	292	445	21.7	21.7	4.8	0.	**4.8**
	Fans with Steam Engines. {Nos. 12 and 13. Report of Prof. Trowbridge of Experiments of G. A. Suter, M. E.								Horse Power.	Coal per H.P.	Lbs.	Lbs.	Cts.	Cts.	Cts.
12	Blackman Fan. Diameter, 4 ft., 340 revs. p. min., thro' free pipe, 30 ft. lg., 4 ft. dia.						27	1,222,320	.76	4.5	3.4	.3	.06	2.0	**2.1**
13	Same, obstructed with Cheese-cloth = Pressure by Water-gauge, .28 inches . . .						13	598,980	1.12	4.5	5.0	.8	.2	4.1	**4.3**
14	Centrifugal Fan. Diameter, 8 ft., 56 revs. p. min., through small flues (Thos. Box)						10	691,200	.25	4.5	1.1	.2	.04	3.7	**3.8**
15	Buffalo State Insane Asylum, 6 Mills Exhaust Fans, 6 feet dia., 3 feet wide . . .						10	4,377,540	Exhaust Steam used for Heating.					0.5	**0.5**
	Fans with Water Motors.								**(Power by Water Motors.)**					Cts.	Cts.
16	School-House No. 10, Buffalo, N.Y., Mills Fan, Diameter 6 ft., Rev. 60 per min., .						9.6	490,000	Water used for other purposes,					0.	**Nom.**
17	School-House No. 13, Buffalo, N.Y., Mills Centrifugal Fan, 6 ft. Dia., 3 ft. wide, .								Water used for other purposes,					0.	**Nom.**
18	Hampden Co. Court-House, Springfield, Mass., 2 Mills Fans, 6 ft. Dia., Rev. 55,							426,242	431 gals. per hour, at 15 c. per M.					0.	**1.5**
19	Hampden County Jail, Springfield, Mass., 3 Fans, 6 Feet Dia., 3 feet wide, " 65,						10	748,735	700 gals. per hour, at 15 c. per M.					0.	**1.4**

Mills System of Water Heating and Mech. Ventilation—Trinity Church, Boston, 1888, and Eliot Cong. Church at Newton, Mass., 1889.

☞ References to Nos. 15, 16, 17, 18 and 19. Pages 112, 523, 566, 447, and 575.

PROFIT AND LOSS IN SCHOOLHOUSE VENTILATION.*

The difference between the cost of simple heating and heating with free ventilation is not so easy of exact statement, but may be closely approximated. Taking as an example a brick-walled school building 96 feet by 92 feet by 37 feet, having a mansard roof and 1,200 square feet of single-glazed window surface, estimate makes the coal required for heating alone for 30 weeks, and including that lost in banking fires, 83 tons, at a thermal efficiency of 8,000 units per pound of coal. Through faulty firing and wasteful methods of heating, this amount may be exceeded by 15 or 20 tons. An air supply of 1,500 cubic feet per hour per capita for 6 hours a day and 5 days a week would, for the same time, require 32 tons, and this alone could be charged to ventilation. At $5 per ton, the year's cost per scholar would therefore be 27 cents, or a total of 52.5 cents a year, or a little under 2 cents per week for the 30 weeks of required artificial ventilation.

Such estimate takes no account of the waste attending the usual methods of heating, without or with only meagre ventilation, by which the ceiling air is sometimes 20° overheated to keep the floor at comfortable temperature, or the top floor overheated for the sake of warmth in the lower stories. The effect of this common condition of things upon coal combustion is more than equivalent to the economical heating of the building in a climate with a mean lower temperature of 10°, since loss by conduction through walls is proportional to the mean temperature difference between inside and outside air, and the air lost by leakage is increased in quantity and temperature, — for it is the hottest that escapes; and, the more rapid the outward leakage at the top, the higher the rate of inward leakage at bottom, necessitating a further heating to maintain a comfortable temperature at the floor of a room or the basement of a building. The loss by conduction and leakage is least when a uniformity of temperature is maintained throughout a building or room; and, the more free and efficient the ventilation, the more sure the attainment of that result.

An illustration of this fact is furnished by the records of the heating and ventilation of the two principal buildings of the Massachusetts Institute of Technology. The Rogers Building is heated and ventilated in only a few of its most crowded rooms. The new building, of approximately the same size, but with much larger window surface and thinner walls and more open interior, is ventilated to an extent equivalent to the complete change of the air of its rooms every 12 to 13 minutes; or, assuming 400 occupants, with an average of over 8,000 cubic feet per hour for each occupant, and the ventilation is maintained through an average of 9 hours for 6 days of each week of the school year.

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* Abridged from Notes of S. H. Woodbridge, A. M., Mass. Inst. Technology.

The most perfect record thus far kept shows that for heating and ventilating the new building, 55 per cent more fuel has been required than for heating the Rogers Building, the latter having the further advantage of waste heat from the boilers and heated chimneys, and the regular heating of one of its large rooms, and, in some weathers, the heating the entire building from the new building's boilers.

Such evidence would make it appear that the difference of 32 tons estimated as the cost in fuel of ventilation, above simple heating, is too much, rather than too little, to be charged to that account. Taking, however, an estimate of 2 cents per week as the maximum actual cost per pupil, it is safe to declare that a very small payment for the actual monetary gain secured.

By way of illustration, the Pension Office data are again suggestive. Let the total 700 tons of coal burned during the year covering the data quoted (at $4 per ton), represent the cost of improved ventilation, and let 8,622 days, at an average of $2 per day, saved from illness, represent one item of the resulting profit. The account of profit and loss would then stand, — profit, $17,244, and loss, $2,800; no account being made of the improved working ability of the whole force, nor of the private account of the unincurred expense incident to 8,622 days of sickness.

An estimate of the immediate dollar and cent profit due to averted illness may be based on the record of a large grammar school covering absences because of sickness. Considering the value of a day saved from sickness worth no more than the cost to the city of one day's schooling, and assuming medical attendance on one in twenty-five cases of sickness, and the cost of substitution at $1 a session (the absence of teachers through sickness being given the same ratio as that found for the scholars), the profit side is then found to exceed the total loss by more than 20 per cent.

All the suffering involved in five and one-half years of sickness, all the gain in the character and quantity of work done both in and out of the schoolroom, and the increased vigor of health maintained throughout school years and after life, though of incomparably greater value, count for nothing in such an estimate. Were five and one-half years of sickness directly caused by some public mal-administration other than the keeping of fresh air out of schoolrooms, the yearly draught on its treasury for damages might easily be largely in excess of the total cost of the construction and use of a good ventilating system. Classified according to the air allowance, as determined by the air space in houses to the individual occupants, the last year's official report for the city of Dundee, Scotland, shows the effect on death rate and longevity as follows: —

Proportionate Air Volumes	1	2	3	4
Proportionate Death Rates	21.4	18.8	17.2	12.3
Average Ages of those Dying between 5 and 20 years .	7.	8.3	12.2	11.7

POWER THAT MAY BE DERIVED FROM THE HYDRANT.

*It was not at first apparent, and is still a matter of surprise to many, how little pressure is required at one end of a pipe or column of air to cause motion sufficient for all purposes of ventilation; and yet, small as that pressure is, it represents a certain and definite amount of work, whether it is done by means of a heated flue or whether it is secured by means of the rotation of a machine called a fan, and driven by some other motor employing steam, wind, or water as its impelling force.

The question of the total power absorbed in driving any class of fan wheels moving air at low velocities and pressure required in ventilating operations, is not of great moment, except where steam power is not available, since a quarter or even half of a horse power is not a serious matter, the total cost being covered, as seen (table No. 39), *by two and four cents per one hundred thousand cubic feet of air moved at a velocity of twenty-seven and thirteen feet per second, respectively.* In places, however, where steam power is not available or not suitable, owing to the uses of the structure, the necessary power to operate a fan is an important issue, and one that will determine the question whether mechanical ventilation can be at all considered. Since, however, electrical power is becoming so common and reliable, at least in cities and the larger towns, it disposes of one of the main obstacles to fans in churches, schoolhouses, and even the dwellings.

Power to operate the Fan.—Having ascertained how small a power would cause the necessary rotation of a specially constructed wheel, the selection of the motor was next in order, or rather the adjustments of two special machines to work in harmony together. Water was adopted as the most desirable power to employ in church and school buildings, because it is there, and is already the property of towns and cities, and in most cases can be made to do double duty, serving the sanitary appliances after passing through the motor; still it was deemed desirable to have some practical data as to how much real work could be obtained from this class of jet or impact water motors, especially as parties having impact or pressure motors continually claimed the greater efficiency for their respective wheels.

In July 1886, the writer being at Westfield, it was decided to proceed to a final and practical test of the efficiency of two impact wheels and one piston motor, at that time confidently believed to be a superior machine for the transmission of water power.*

Not having time for so delicate and important a matter as this, the services of an educated and practical engineer were secured, who, after careful preparation, and with the aid of two assistants (at the end of three days' constant and repeated tests), secured the data, estimates, and diagrams, shown in the following pages.

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* See table of experiments No. 37, page 561.

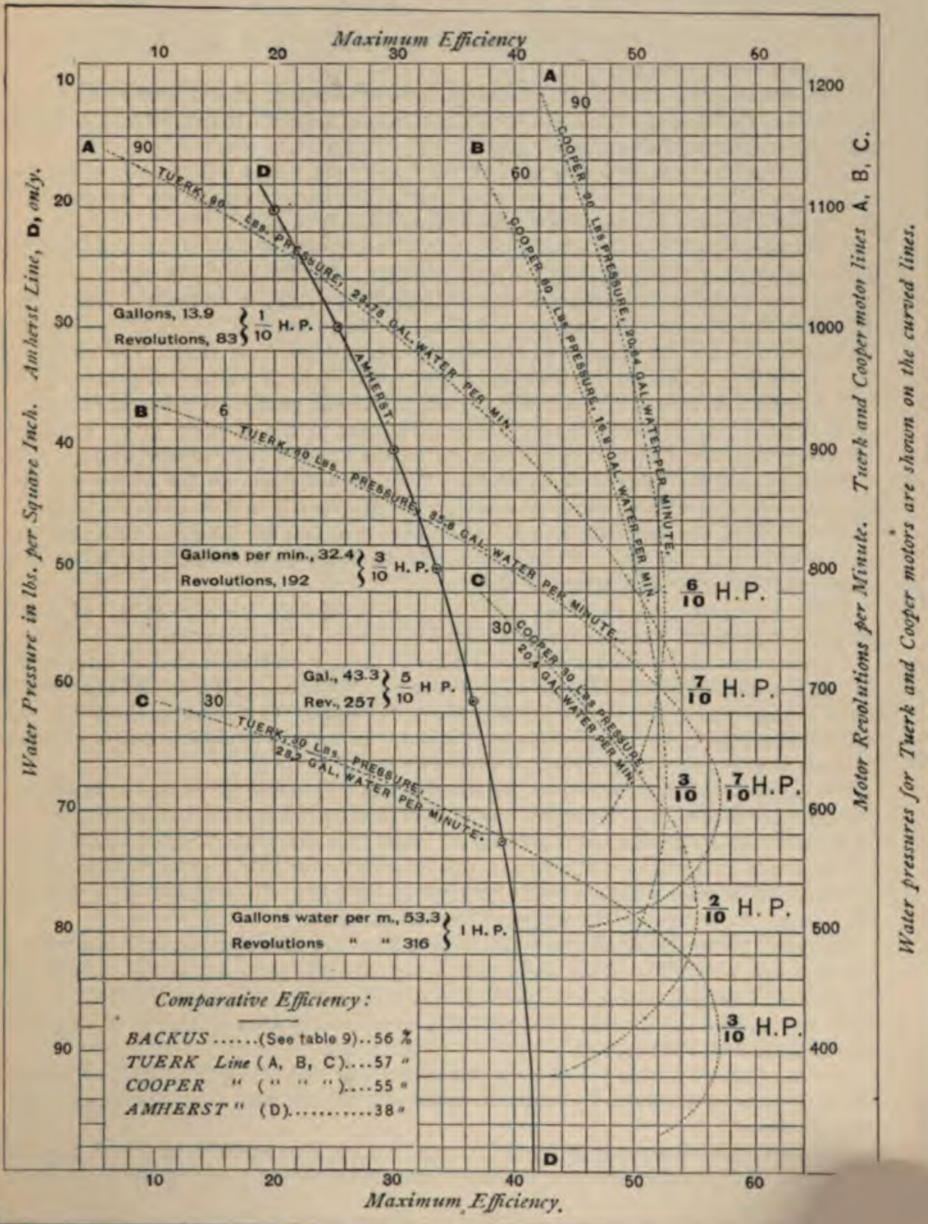
DIAGRAM No. 34.

Showing the maximum and average efficiency of

BACKUS, TUERK, COOPER and AMHERST WATER MOTORS.

Experiments, and Report of

LESTER P. BRECKENRIDGE, JULY, 1886.



WATER MOTORS.

REPORT OF EXPERIMENTS ON THE "COOPER" AND "TUERK" MOTORS, BY LESTER P. BRECKENRIDGE, WESTFIELD, MASS., JULY, 1886.

To accompany Diagram No. 33.

The object of the tests was to obtain the efficiency of the above-named wheels under pressures from 1 to 100 pounds per square inch.

Pressures. The Cooper wheel increases its available power under the same pressure by changing to a larger nozzle. The Tuerk increases or diminishes its available power under the same pressure by opening or closing a conical valve attached to the motor.

Nozzles. The Cooper motor was tested with nozzles $\frac{3}{32}$ inches, $\frac{1}{4}$ inch, $\frac{5}{16}$ inches, and $\frac{3}{8}$ inch, made of brass.

Horse-Power of the Wheel. The horse-power of the wheel was determined by a friction brake; the horse-power in the water by means of a carefully-gauged tank holding 4,800 pounds (576 gallons nearly).

An explanation of the diagram marked "A" will be all that will be necessary, for the diagrams "B" and "C" were obtained in the same way, except for different pressures. For revolutions of the wheels, see diagram No. 34.

The Cooper motor was tested under 90 pounds pressure with the 4 nozzles mentioned above, and the $\frac{5}{16}$ nozzle gave the best efficiency. This curve therefore appears on A as the best the Cooper motor could do under 90 pounds pressure. The Tuerk was also tested under the same pressure, and it was found to give the best efficiency when the valve on the motor was turned 2 times around from shut. The curve on A, marked Tuerk, is then the best this motor could do under 90 pounds pressure. It will be seen that from 600 to 700 revolutions, the Tuerk gave a little better efficiency than the Cooper. Above 730 revolutions per minute the Cooper gives a better efficiency than the Tuerk, with any nozzle on the Cooper, and valve opening up to 4 turns (when the valve is open wide). The efficiency curves for 90 pounds are approximately parallel to the curves shown on diagram A, and the efficiency varies not much from the same curves, so that these curves may be taken to represent the comparative value of the 2 motors, as far as efficiency goes, under 90 pounds. The same remarks apply to diagrams B and C.

The temperature of the water was 65° Fahr., and the weight of one gallon of water at this temperature was taken at 8.33 pounds (1 gallon, 231 cubic inches).

The experiments would indicate that it is the form of the buckets and their number that control the efficiency to a large extent. With any given nozzle the wheels gave approximately the same efficiency at all pressures. This tends to show that the frictional losses in the machine are very small. In fact, $1\frac{1}{2}$ pounds pressure sufficed to keep the Cooper wheel in motion without a load.

The largest power developed during the test was 1.62 horse-power, under 90 pounds pressure by the Tuerk. The valve was opened three turns, and the efficiency obtained was 46.98 per cent, using 65.3 gallons of water per minute. When developing 1.2 horse-power under the same pressure, this wheel gave an efficiency of 52.34 per cent. It is probable that with the valve further opened the wheel would develop fully 2 horse-power, with an efficiency of at least 40 per cent.

The most power obtained from the Cooper was .932 horse-power, and this with a $\frac{3}{8}$-inch nozzle under 90 pounds, and an efficiency of 51.31 per cent, using 34.3 gallons of water. A larger nozzle, $\frac{1}{2}$ inch and $\frac{5}{8}$ inch, would, without doubt, develop a power fully as large as the Tuerk, with, perhaps, an efficiency approximately as large, at least within 2 to 3 per cent.

The least power developed that was measured was .05 horse-power, by the Cooper, using $\frac{3}{32}$-inch nozzle and 5.8 gallons of water per minute under 30 pounds, showing 49.5 efficiency.

The least power developed by the Tuerk was .06 horse-power, under 25 pounds pressure, using 22.37 gallons per minute, and showing an efficiency of 18.42 per cent.

The horse-power of the water was determined by the following formula: Horse-power = W x F ÷ 33,000, in which W equals the weight of the water in pounds passing through the wheel per minute, and F equals the distance in feet that the water fell. W was determined by means of a tank holding 4,800 pounds, F by means of a pressure gauge, assuming 2.33 feet as the height of a water column producing 1 pound pressure per square inch.

The efficiency of the wheels was obtained by dividing the horse-power of the wheel (as determined by the friction brake) by the horse-power of the water.

Amherst Motor. The wheel was allowed to run several hours before starting the tests, in order to soften the leather plungers of the eight pistons, and also to thoroughly lubricate the different bearings.

Among the sources of loss in this motor, *and all piston motors*, are — first, friction in the moving parts of the machine itself; second, friction of the water through the pipes, valves, and ports; third, change in the direction of motion of the water; fourth, change in the velocity of the moving water due to difference in area of the passages; fifth, water, after use, must be driven from the cylinder in which it was used.

It required a pressure of from 15 to 18 pounds to start the motor under no load, except the frictional resistances in itself.

From these considerations we can see that the sources of loss of effect will not increase as rapidly with the water pressure as the obtainable work. We shall, therefore, expect to find the efficiency increase with the water pressure.

The calculated delivery per hundred revolutions is 15.3 gallons of water (8 plungers, 1½ inches diameter, 2½ inches stroke). The actual delivery was 16.874 gallons per hundred revolutions, corresponding to a leakage of 1.574 gallons per hundred revolutions. For revolutions of the wheels, see diagram No. 34 and table No. 38.

At 80 pounds pressure; 16.874 gallons of water per 100 revolutions. Horse-power = .952 ÷ .3825 = 2.49 horse-power. Water x 33,000 = 82,170 foot pounds per minute. Water, 19.26 x 80 = 1,540.8 foot pounds per gallon. 82,170 ÷ 1,540.8 = 53.33 gallons water per minute ÷ 16.874 = .316 x 100 = 316 revolutions per minute. 38.25 per cent efficiency = .952 horse-power by brake.

At 70 pounds pressure; 45.91 gallons water per minute; revolutions per minute, 272; 36.50 per cent efficiency = .685 horse-power by brake.

At 60 pounds pressure; 43.3 gallons water per minute; revolutions per minute, 257; 33.50 per cent efficiency = .508 horse-power by brake.

At 50 pounds pressure; 32.45 gallons water per minute; revolutions per minute, 192; 30.03 per cent efficiency = .284 horse-power by brake.

At 40 pounds pressure; 28.23 gallons water per minute; revolutions per minute, 167; 25.5 per cent efficiency = .168 horse-power by brake.

At 30 pounds pressure; 13.94 gallons water per minute; revolutions per minute, 83; 20.09 per cent efficiency = .049 horse-power by brake.[*]

Cooper Motor, 90 pounds pressure, 20.64 gallons water per minute. Power applied in the water = 19.26 x 90 x 20.64 = 35,777.38 foot pounds per minute ÷ 33,000 = 1.084 horse-power. The power realized by friction brake taken at 52 per cent of the power applied = 1.084 x 52 = .56 horse-power.

At 60 pounds pressure; 16.8 gallons of water per minute; 52 per cent efficiency horse-power realized = $\frac{3}{10}$.

At 30 pounds pressure; 20.4 gallons water per minute; 56 per cent efficiency = $\frac{2}{10}$ horse-power realized.

Tuerk Motor, 90 pounds pressure; 23.78 gallons water per minute; 52 per cent efficiency = $\frac{7}{10}$ horse-power realized.

At 80 pounds pressure; 35.8 gallons water per minute; 57 per cent efficiency = $\frac{5}{10}$ horse-power realized.

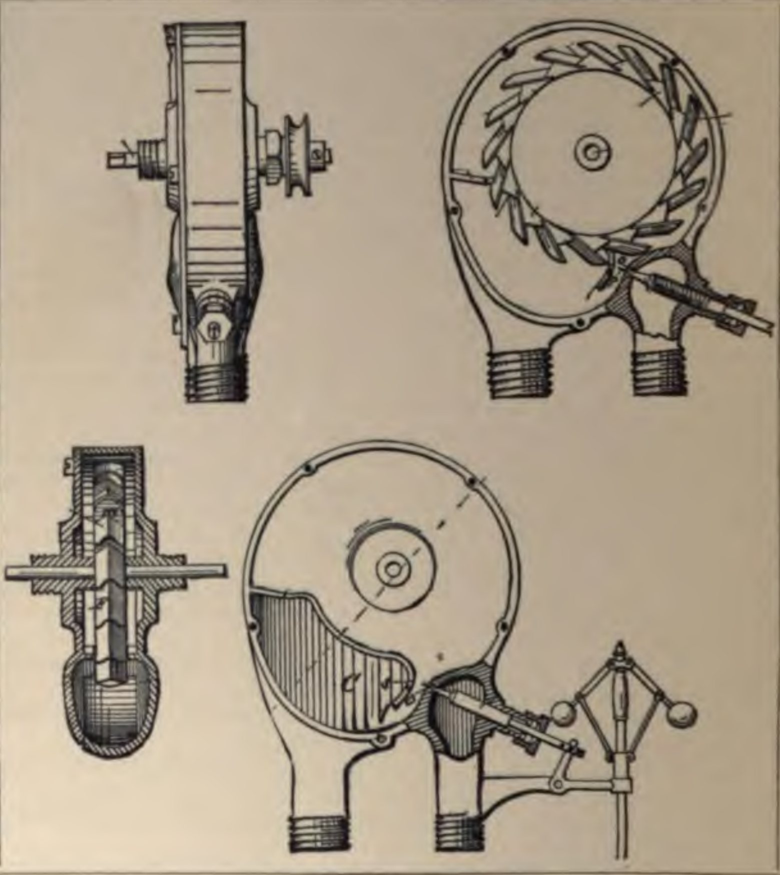
At 30 pounds pressure; 28.2 gallons water per minute; 57 per cent efficiency = $\frac{3}{10}$ horse-power realized.

[*] This wheel has since been abandoned and replaced by a more efficient machine, called the *Benham motor*. The Backus motor was tested previously. See table No. 37.

DIAGRAM No. 35.

THE TUERK WATER MOTOR, AND GOVERNOR FOR JET MOTORS.

Diagram No. 34 shows work-lines from the Tuerk and Cooper Motors and efficiency, 52 to 56 per cent. See also Experimental Table, No. 38, and accompanying Report on Motors, by L. P. Breckenridge.



The cuts show the several parts of the wheels and Governor for automatically controlling the speed. The diagram also practically illustrates the class of impact or jet motors like the Backus, Cooper, Binghampton, and others.

TABLE No. 40.

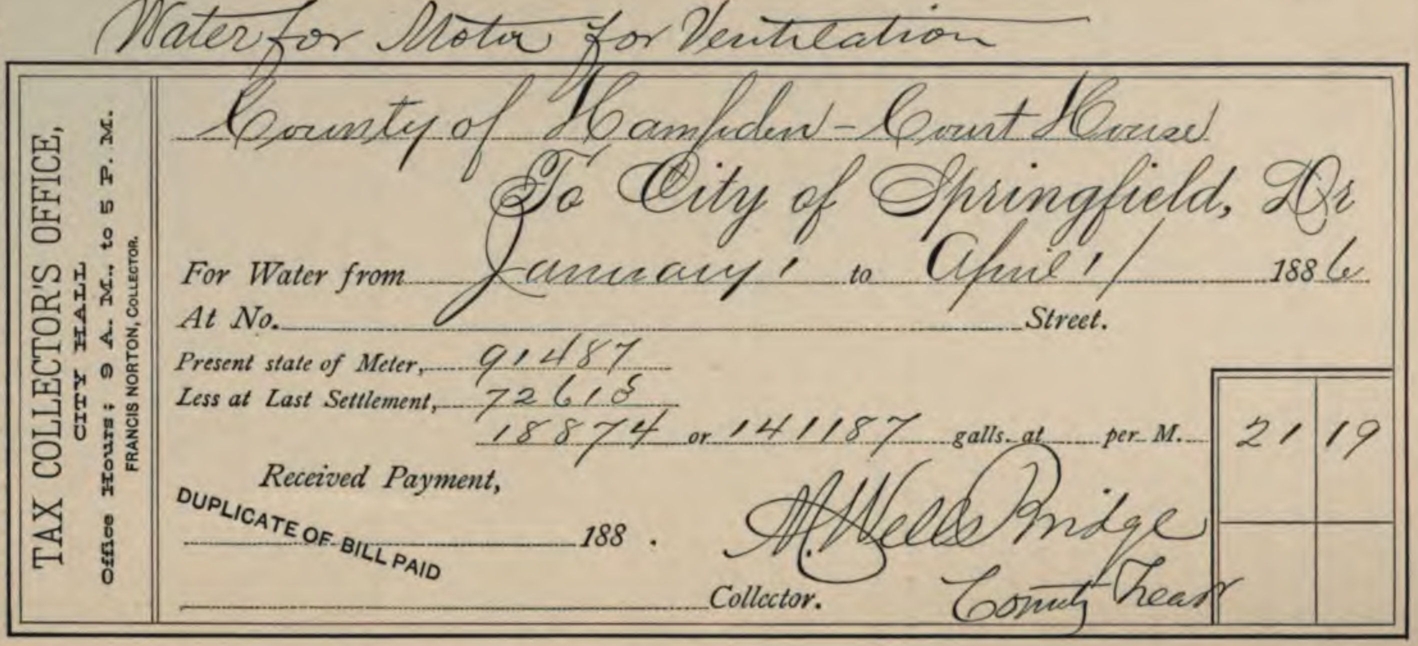
Showing the proper working speed of Tuerk's High Pressure Motors in various pressures from 10 to 130 lbs. per square inch. (The meaning of working pressure is actual pressure at the Motor when laboring at its full capacity.) (For No. 8 to No. 13 Motors.)

Pressure. lbs.	No. 8.	No. 10.	No. 11.	No. 12.	No. 13.	Pressure. lbs.	Pressure. lbs.	No. 8.	No. 10.	No. 11.	No. 12.	No. 13.	Pressure. lbs.
	NO. OF REVOLUTIONS PER MINUTE.							NO. OF REVOLUTIONS PER MINUTE.					
20	1080	485	340	225	170	20	60	1880	845	600	395	295	60
25	1220	535	375	250	185	25	65	1960	880	620	410	310	65
30	1340	585	410	275	205	30	70	2040	915	640	425	325	70
35	1440	640	435	300	220	35	75	2120	945	665	440	335	75
40	1540	695	480	325	240	40	80	2180	980	685	455	345	80
45	1640	735	510	340	255	45	85	2240	1010	700	470	355	85
50	1720	770	540	360	270	50	90	2320	1040	720	480	365	90
55	1800	810	570	375	285	55	95	2380	1070	740	495	370	95

TABLE No. 41.

COST OF MECHANICAL VENTILATION BY WATER POWER.

Ventilation effected by one Mills' Double Fan and Tuerk Water Motor, No. 11. Water at 100 lbs. Hydrant Pressure. (See Lower Section, Table No. 40, also Report of Trial of Water Motors at Westfield, Mass., 1886, Diagram No. 34, and Table of Experiments, No. 38).



Water for Motor for Ventilation

TAX COLLECTOR'S OFFICE,
CITY HALL
Office Hours; 9 A. M., to 5 P. M.
FRANCIS NORTON, COLLECTOR.

County of Hampden - Court House
To City of Springfield, Dr

For Water from January 1 *to* April 1 *188*6
At No. .... *Street.*
Present state of Meter, 91487
Less at Last Settlement, 72613
18874 *or* 141187 *galls. at* .... *per M.*

21	19

Received Payment,
DUPLICATE OF BILL PAID
.... *188* .
H. Wells Bridge
.... *Collector.* County Treas

First Floor—Court Rooms, Library, Halls, and Offices, 175,312 cubic feet.

Second Floor—Court Rooms and Offices, 205,169 cubic feet.

Third Floor—Jury Rooms, 32,640 cubic feet. Total, 426,242 cubic feet.

In looking at the conditions of warming and ventilating school and other public buildings to-day, and comparing it with the condition of the same buildings even three or four years ago, much progress may be noted. Still the advance does not seem at all commensurate with the great need and imperative demand for pure air, or with the efforts that have been put forth to secure it.

An examination of the last two reports of the Massachusetts District Police shows that the public sentiment in this State, at least, has progressed far enough to pass strong and comprehensive laws, and that there has been faithful and efficient work by an intelligent board of inspectors, in carrying out, not only the bare letter of the law, but in giving much personal attention to all efforts of those directly concerned in improvements, to secure better sanitary conditions in public buildings.

While we have given in Chapter XXVII. much space and time to the work of this sanitary board, and to the demands of this class of work, we deem it of interest to refer briefly to this last report of Chief Wade (1889, 1890), and to the several methods which he notices as examples of improved ventilation.

The Jacketed Stove. — This method of securing a pure-air supply to small and isolated schoolrooms is hardly new, it having probably originated with Henry Ruttan, and was used by the first Ruttan Company, as may be seen by an examination of their early catalogues. If the Secretary of the State Board of Health has just heard of it, and had it adopted for the Red Rock Schoolhouse at Lynn, it shows how slowly information is disseminated in this particular line of work.

That this is an improvement over stoves without jackets, or an outside air supply, should not need argument or cuts to illustrate. The weak point in any such air supply, dependent on the heat of the stoves to get into the room, is apparent when we consider that in mild weather, and when little heat is wanted, no fresh air would enter. Certainly there should be no difficulty in setting two stoves serving only one room, and operating them satisfactorily, as the report says, "after their working was fully understood."

What is really of value in the data furnished and the illustrations is the actual amount of air that could be supplied in a certain time with so inexpensive and simple an arrangement.

This is clearly due to a more rational and practical application of "ways and means" than to the class or kind of heater employed. After describing the stoves as the Barstow "Puritan," No. 18, the report says: —

"Each stove is encased in a galvanized iron jacket about six and one-half feet high, with a spreading base. Air is admitted to the space between the stove and its jacket by an air box running through the side wall, the opening for each stove having a sectional area of *four and one-half square feet.*

"There are two extraction flues built in one stack at the rear of the building — one with a sectional area of 5.2 square feet for the upper room, and one with a sectional area of 4.1 square feet for the lower room. For heating the flues, one of D. W. Cushing's 'Ring Cylinder' stoves is set. The capacity of the lower room is 10,700 cubic feet; that of the upper, 12,040 cubic feet.

"Measurements of the outflowing air have been made at various times; these show an average for the lower room of 108,510 per hour, or about 2,100 cubic feet to each pupil." This gives, as we see, a velocity at the extraction flue of 441 feet per minute, or 7½ feet per second."

These are substantially the areas of flues required by table No. 26. We are not told what the height of the extraction shaft was or the temperature imparted to the air by the stoves in the vent flues. Lacking this, or the fuel consumed in the two duties — that of warming and that of discharge of the vitiated air — we can make no estimate of the expense in either case; reference to table No. affords, however, a key to the cost.

The report next refers to the Smead system of warming and ventilating. As we have already considered this system in Chapter XXI., page 375, we need not refer to it further, except to note that the methods of the Fuller & Warren Company, of Troy, N. Y., and the so-called Mahoney-Smith system of the same place are substantially copies of the Smead-Ruttan methods, including mixing dampers, dry closets, and jacketed stoves, as fully described and illustrated in their circulars of 1885 and 1889, and with a completeness of detail that ought to prevent any other firm from writing their name over either the methods or means of accomplishment.

Certainly, so far as any hot-air furnace system of warming can answer the demand of this difficult line of work, the Smead people have more to offer than any of those who claim to have improved on their methods or machines.

As of interest to those who desire something safe and sanitary in the furnace line, we may refer to the Hygiean Heater, and a paper on its desirable features by Professor S. H. Woodbridge (page 209A of Report). Our review and illustration of this and other hot-air furnaces may be found in Chapter XXI.

*Returning to the references to methods of warming and ventilating by a steam apparatus, two cuts show the arrangements of A. A. Sanborn and of the Walker & Pratt Manufacturing Company. These do not contain anything novel, or that may be claimed as distinctive over the common practice and experiments in that line.

A steam boiler, some indirect radiator stacks, with the usual cold-air supply, and flues for the removal of the vitiated air are features that Horace Walker employed when the writer was in his service in 1872–73.

The addition of a small coil of pipe in the top of the exhaust flue was used many years ago, and, so far as it goes, is of value in assisting what is otherwise a weak system of gravity circulation.

The mixing damper illustrated and marked "Patent applied for," is not new. It was utilized about the year 1870, and may properly be credited to Charles W. Newton. It has been much used by Levi R. Greene in government work, and many illustrations may be seen of it in the book "Warming and Ventilation," by Dr. John S. Billings, published by *The Sanitary Engineer*, 1884.

The weak points in the use of coils of steam pipe in the exit flues to increase the discharge of air are: First, in putting them at the *top of the flue, and second, in the very limited amount of surface employed.* That such heating surfaces to be effective should be placed at the *bottom of any exit flue*, may be seen with the least effort; since the value of any heat imparted to a vertical column of air is in proportion to its *height or distance below the discharge outlet.* This is fully considered in Chapter XXVIII., page 529.

Of course, if the heating surface is placed at the bottom of a vent shaft, all vent flues from stories above the first, must be brought down and entered below the surfaces intended to heat the air, and this is just what nearly all practical furnace men do; they bring all their discharge flues down to the basement, and enter the shaft at that point.

The other error, as we have said, was in not using enough heating surface to raise the volume of the air in the flue to insure a rapid movement. We have seen (table No. 24, page 531) that the *differences* of temperature between the air outside and that in the flue must be 50° to 60°, or that the air in the flue must be 50° or 60° hotter than that of the room. To add this much heat to the air (table No. 25) requires one foot of pipe surface to each 380 or 400 feet of air to be lifted and discharged per hour; and to move 100,000 cubic feet of air per hour (at a velocity of 4.2 to 5 feet per second) *requires* 263 *square feet of pipe surface.* Crediting a hot-air furnace plate with three times the value of a steam-pipe coil, there would be needed 87 square feet to effect the stated discharge of air. See page 565 and table No. 25, page 569.

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* Report of Rufus R. Wade, 1870.

"During the past year a new and complete system of ventilation has been placed in the Brookline Town Hall, at a cost of $3,900, and electricity provided for lighting. In the main audience room 8 inlet ducts are provided for the admission of fresh warm air. Six have a register face 20 x 28 inches square; 2 have a register face 16 x 27 inches square. For the exit of foul air there are 9 ducts provided — 4 on the base or floor line, with a register face 19 x 25 inches square; 2 in the gallery in the rear of the hall, each with a register face 20 x 28 inches square; 3 in the ceiling, 5 feet 4 inches in diameter, each connecting with the air chamber by a 30-inch flue, with a damper in the flue above the register. The area of the hall is 288,020 cubic feet, with a seating capacity of 1,000 persons. The metal ducts from the hall, with those from other sections of the building, are connected with a large chamber in the attic, 11 feet 5 inches long, 10 feet wide, and 5 feet deep, through which the air is exhausted from the hall by means of a fan, 6 feet in diameter, of the A. Hun Berry pattern. This is operated by an electric motor, belted to an Evans friction-cone pulley, regulated at the present time to run the fan 250 revolutions per minute; and it can be so adjusted as to operate the fan at any speed desired within a reasonable number. All the machinery, together with the fan and air chamber, is suspended from the roof trusses, padded with rubber to deaden the sound, caused by the running of the motor and fan.

"From the base of the hall there are carried away 8,000 cubic feet of air per minute, or changing the atmosphere in the room about once in 30 minutes; this without the use of ventilators in the ceiling. Should it become necessary to remove the air quicker, then these additional openings can be brought into use, and with a velocity of 600 feet per minute, the fan will remove 17,000 cubic feet of air per minute. There is no reason why any person should complain of poor ventilation in this building, provided both heating and exhausting ducts are in use.*

"BELMONT STREET SCHOOL, WORCESTER, MASS.—Is a 3 story and basement brick building, of 18 rooms; average attendance, 800. All of these rooms were connected to 1 foul-air shaft, 8 feet 1 inch x 7 feet 9 inches. The fan was an 8-foot Blackman disk wheel, driven by a 6 x 10 = 6 horse-power steam engine (pressure 60 pounds). A test was made, November 20, in the above building, with the following results: Weather, raining; temperature outside, 50°; temperature near fan in foul-air shaft, 68°; velocity at foot of shaft, 700, showing 41,300 feet of air moved per minute. The average temperature in the rooms was 70°; amount of air removed, 1,335 feet per minute, an average of 29⅓ feet per pupil. The temperature of the air entering room was 93°. Average of tests made for carbonic acid, 6⅒ in 10,000 parts."

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* Kendrick Brothers, contractors, Brookline, Mass.

Clearly the whole value of any heating or ventilating machine depends on the kind, size, and general intelligence brought to bear on the apparatus. As we have already partly considered the furnace and house-heating question in Chapter XXI. (pages 373 to 390), we do not follow it more at length here.

A close stove in a room without an air supply has been justly condemned as an unsanitary means of heating; this mainly for two reasons: The first is the high temperature of the heater, and the fact that it only warms the same air already in the room from day to day and week to week, so that finally the condition of impurity reached by such air renders it both disagreeable and dangerous to inhale.

Still the close stove is not a worse device than the direct radiator, except so far as temperature is concerned; since the stove really does withdraw a certain and considerable amount of air from the room, an amount, as we know, equal to at least 150 cubic feet of air per pound of coal burned; and if but two pounds of coal were burned per hour, these 300 cubic feet and the further amount that is drawn up the flue by the air-check damper, will suffice for the ordinary needs of one person.

The direct radiator, as we know, performs its work by heating in the same way as the stove, but with lower temperature, minus the labor, dust, and annoyance of coal in the room.

In this connection it may be well to note, that in other places besides dwellings it is common to employ direct radiators, and it may also be desirable to obtain an outside air supply.

Sometimes this is done by placing the radiators at the window and admitting the air behind them, as shown on page 363. Another, and we consider the best, way to secure a liberal amount of pure air in connection with direct radiation is illustrated in Chapter XXIII., page 315. Here the radiator is circular, and, the base being hollow, will admit a pipe 12 inches in diameter; the tubes forming the screen around the pipe and damper; this is also the cheapest way to secure a pure supply of outside air to large rooms and halls.

The gain really found in steam or water heating is in placing the radiation in chambers in the basement, and connecting them with the rooms and the outside air, *by which means heat and a constant supply of pure air are secured.*

Enough has already been said concerning the evils of heating the air of a room without provision being made for frequently changing it. *It needs only to be noted here, that nothing is more certain to produce these evils than direct radiation when used as the only means of heating.*

This must not be considered an argument against direct radiation in itself, *but by itself;* indeed, it should form a part of all steam heating. *It is here condemned only when used exclusively.*

CARE OF IMPROVED HEATING APPARATUS.

[*] "The selection of a janitor for school buildings, under an improved system of heating and ventilation, should be a more important matter for consideration than in the past. The janitor should not be a mere drudge or common laborer, but in some sense a man of education in concerns which affect the welfare of the children, relative to their health, and that of the teachers. To have the school building well heated and ventilated, he should not merely make up and set his fires and apparatus in order, and go off and leave them for any considerable time, as, in some instances, taking care of two or more schoolhouses; but he should be present during sessions, to see that everything is safe and in good working order. His position should be little less than that of an engineer; and the consequence of his neglect may be much more disastrous than that of a careless and bungling engineer. In the faithful discharge of his duties he will find much to do, especially in the large school buildings. In the experience of every housekeeper, it is found that there may be a great saving of fuel by a constant attention and care of the fires; so, in the large consumption required in school buildings, the janitor may save an equivalent equal to the necessary increase of salary where more ability and time are among the requisites of the position.

"The additional duties imposed upon him cannot be expected to be performed by one who is anxious to lighten his labors and go about some other business, nor by one who takes no other interest in his business than merely to draw his salary. One of the duties, as specified in the rule of a school committee, is: That the janitor shall inspect all the apartments and out-buildings, with their surroundings, at least once daily, and he shall be held responsible for their cleanliness at all times; likewise, he shall, in conjunction with the teacher, investigate all abuses of sanitary accommodations, and report the same to the committee.

"It is believed that a janitor should be able to pass an examination as to his fitness to manage the improved appliances in heating and ventilation. An excellent method has recently been adopted in the town of Peabody, under the direction of the Chairman of the School Committee. A meeting was recently held of all the school teachers in that town with the janitors and the School Committee, in which the subject of ventilation was thoroughly discussed, and with good results."

It should be remembered and impressed on the managers of public institutions, that every system of heating and ventilating apparatus requires constant care as to its cleanliness, efficiency, and adjustment to the demands of the season and the hour, to produce the best results, and that the most wasteful of all expenditure is to provide an elaborate and costly apparatus, and then intrust it to the care of an ignorant or careless engineer, on the ground that he is somebody's "nephew," or is "an active politician."

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[*] **Rufus R. Wade's Report of 1890.**

"The requirements of good ventilation and heating being understood, the best method or arrangement for carrying out such requirements presents itself. This will be found to be the stumbling block over which many an engineer and architect has tripped. Natural agencies, as apparently the least expensive, have usually been first called upon to produce currents and move such volumes of air as might be required.

"But it will be admitted and shown that all systems of 'natural ventilation' have proved themselves inadequate to fulfill modern requirements. A dependence on windows and doors for ventilation cannot with propriety be called a system of ventilation; for the supply is ordinarily spasmodic, and without question disagreeable, except in so far as a cold draught of fresh air from an open window may be preferable to the vitiated and odorous air of a confined apartment. Excellent results may continue for a number of days during the employment of a method of ventilation dependent on natural agencies; but a change in the temperature or humidity, or in the direction and force of the wind, may exactly reverse the action of the system. Flues which were designed to furnish fresh air, will be found to be actionless, while exit flues may be bringing foul air from other rooms. So, too, although to a lesser degree, in the case of currents induced by heated surfaces, steam, or air jets. Above all, these latter experiments will be found to be very expensive when the power required to develop this movement is taken into account. All such systems are entirely unequal to the task of supplying air in such quantity as has been shown to be required."

There are some good systems of natural ventilation now in use, or a movement of air caused by heat, the inventors of which deserve credit for good work toward solving the great problem of warming and ventilating. But the efficiency of none of these systems is commensurate with the claims of the designers.

It has already been explained how heating and ventilating are antagonistic processes, ventilation being always at the expense of heat. In any method of heating, ventilation must be provided for and arranged as an accessory to the heating. No heating apparatus is in itself a ventilator. Good ventilation is possible with any system of heating, as no ventilation at all frequently accompanies good methods of heating, when in themselves considered.

That poorly ventilated schoolhouses are sometimes heated by steam, is no argument against steam as a method of warming; nor does it prove that good ventilation is not possible with steam heating.

Although fully explained in former pages, it may here be restated that there is a most marked saving in heating surface when a system of indirect radiation is used in connection with a fan in place of the ordinary method of construction.

THE DESIGNING OF HEATING AND VENTILATING SYSTEMS.

The problems connected with ventilating buildings are as many as the numbers of the buildings. Each house has its peculiarities. There is no way of applying a given "system" to all cases without modification.

It is a difficult undertaking to design and carry out a complete system of ventilation and heating without extended experience. The state of the art at the present time is fairly well understood in theory, but very poorly carried out in practice, and many failures are registered against mechanical ventilation. This is the natural result of the attempts made by inexperienced builders and contractors to apply the established principles of ventilation and heating without regard to the modifying influences that entirely determine the efficiency of any system. The principles are correct enough, but failure results from a misapprehension and misapplication of them.

It does not matter what system of ventilation is proposed, the same difficulty presents itself; namely, the proper size and location of the shafts and power to render them operative. When the architects recognize the fact that proper ventilation must be provided for as fully and as well as for *water*, *heat*, *and light*, the greatest difficulty will have been overcome. Then with intelligent coöperation on the part of the owner, the architect, and the ventilating engineer, a perfect system of air supply and removal will be the result.

It must not be forgotten that ventilation is a science — a science of designing and applying means that shall, under various conditions, always secure a proper inflow of pure air and expulsion of foul air, so nicely equalized as to be free from anything detrimental to health.

A ventilating engineer who claims to be an expert, should be able by his system, or apparatus, to handle the air in given quantities; to say positively he will bring into a room so many cubic feet of air per minute. In order to do this, he must determine carefully the size of the fresh-air inlet and the foul-air outlet, to attain the desired end. He must not rely on accidental differences of weight between inside and outside atmosphere to produce movement of the air. There must be little of a *theoretical* nature about his calculations.

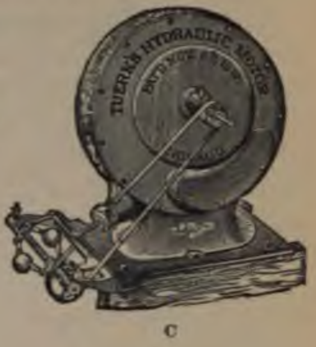
If an architect, engineer, or any other person makes plans and specifications for the details of heating and ventilating apparatus, and receives pay for such service, the adequacy and efficiency of such plans should be guaranteed by the party making them, and he should be held responsible to those who employed him. That this is the right view, is seen and applied where a contractor executes any detail of work prescribed by an architect; the workman cannot be held responsible for only the proper mechanical execution of the plan which the architect has made.

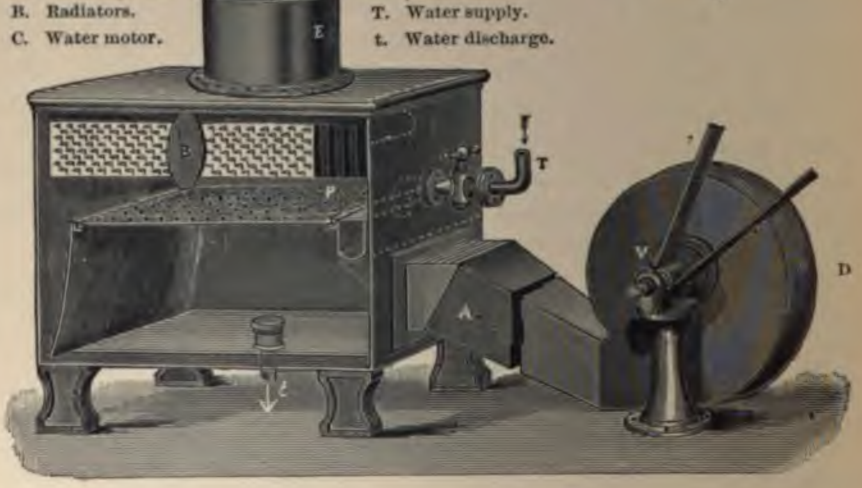
FIGURE No. 27.

APPARATUS FOR HEATING, COOLING, AND MOISTENING AIR.

FOR USE IN HOSPITAL WARDS OR SINGLE AND PRIVATE ROOMS.

With this portable apparatus any desired condition and amount of air can be obtained, even at a distance from the source of heat, or a water stove may be attached and the same conditions secured in any building or room. In cooling the air, the water that moves the fan is discharged first through the radiator, then on to the perforated plate, P.





In adding moisture to the air, either with or without heating, the water from motor is discharged into pipe, T, and through plate, P, to drain or to a tank for supplying *water closets or urinals.*

By constructing a few chambers in hospitals, the quality of the air that passes the zone of respiration might be entirely under control, medicated, heated, dried, moistened, cooled, and applied in any quantity, as circumstances might dictate, and a more specific power would be obtained, capable of being applied advantageously to many cases of disease.

The whole apparatus, being of galvanized iron, may be placed anywhere, even in the rooms to be warmed or cooled.

A very desirable arrangement for dining-rooms in warm weather is to receive cool air instead of warm.

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BOOKS AND PAPERS CONSULTED AND REFERRED TO.

ON HEAT.

Combustion . . . . W. E. Dimond (condensed in Part First).
Knight's Mechanical Dictionary . . . . First, Second, and Third Parts.
Appleton's Cyclopedia. *Tomlinson's Cyclopedia.*
Inorganic Chemistry . . . Thorpe, 1873, "Youman's Atlas of Chemistry," 1854.
Natural Philosophy . . . . Rolfe and Gillett, 1874.
A Practical Treatise on Heat . . . . Thomas Box, 1876.
Theory of Heat . . . . J. Clerk Maxwell, 1872.
A Simple Treatise on Heat . . . . W. M. Williams, 1880.
Heat as a Mode of Motion . . . Tyndall, 1873; "Heat," Chas. W. Williams, 1841.
Heat and Heat Engines . . . . Prof. W. P. Trowbridge; John Wiley, 1874.

ON FUELS.

Fuel; Its Combustion and Economy . . . . D. K. Clark; Van Nostrand, 1879.
Combustion of Coal . . . . Wm. M. Barr; Yohn Bros., Indianapolis, 1879.
Fuel . . . . J. Wormald, "Van Nostrand Science Series," 1874.
Petroleum and its Products . . . . S. F. Peckham, "U. S. Census Reports," 1885.
Liquid and Gaseous Fuels . . . . . . "Scientific American" and other Journals.
Chemical Technology, Vol. I., Fuel . . . . Mills & Rowan, London, 1889.

ON STEAM BOILERS.

A Treatise on Steam Boilers . . . . Robert Wilson, London, 1873.
Steam Boiler Explosions . . . . Robinson; Little, Brown & Co., 1870.
Steam Boilers . . . . Wm. M. Barr; Yohn Bros., Indianapolis, 1880.
Useful Things to Know about Steam Boilers . . . . G. B. N. Tower, 1885.
A Manual of Steam Boilers . . . . Prof. R. H. Thurston; J. Wiley, 1888.

ON WARMING AND VENTILATION.

Illustrations of the Theory and Practice of Ventilation . . . . Reid, 1844.
Warming and Ventilation of Buildings . . . . Charles Hood, 1879.
Warming and Ventilation . . . Tomlinson, "Weales Scientific Series," 1864-1878.
Warming and Ventilation . . . . Henry Ruttan, 1862; I. D. Smead, 1888.
Mechanics of Ventilation . . . . Rafter, 1878; Butler, reviewed by Greenleaf, 1885.
Ventilation of School Buildings . . . . Morrison; D. Appleton & Co., 1887.
Steam Heating . . . . Robert Briggs, "Van Nostrand Scientific Series," 1885.
Our Dwellings Warmed and Ventilated . . . . J. W. C., 1875.
Ventilation . . . . Gouge; Van Nostrand, 1870, Lewis W. Leeds, 1880.
Steam Heating for Buildings . . . W. J. Baldwin; Jno. Wiley & Sons, N. Y., 1881.
Hot Water Heating and Fitting . . . W. J. Baldwin, "Eng. and Build. Rec.," 1889.
Ventilation and Heating . . . . Dr. John S. Billings, "The San. Engineer," 1884.
Steam Heating Problems . . . . "The San. Eng." N. Y., 1887.

MISCELLANEOUS.

Heating by Steam . . . . J. H. Mills, Boston, 1878.
Heating and Ventilation . . . . Schuman, 1877.
Report of the Mass. District Police . . . . Boston, Mass., 1889-1890.
Report on the Ventilation of the U. S. House of Rep., Robert Briggs, C. E., 1876, 1881.
Report of Prof. Trowbridge on the Relative Cost of Ventilation by Fans and Chimneys.
Health and Comfort in House Building . . . . . Drysdale & Hayward, London.
Report of the U. S. Centennial Exhibition . . . . Gen. F. A. Walker, 1876.
Proceedings of the Boston Academy . . . . Dr. Morill Wyman, 1858.
The Master Steam Fitter. *The Manufacturer and Builder* . . . . . Chicago.
The Sanitary Engineer (*later the Eng. and Building Record*), *The American Machinist*, *Scientific American and Supplements*, N. Y.; *Modern Light and Heat*, Boston.

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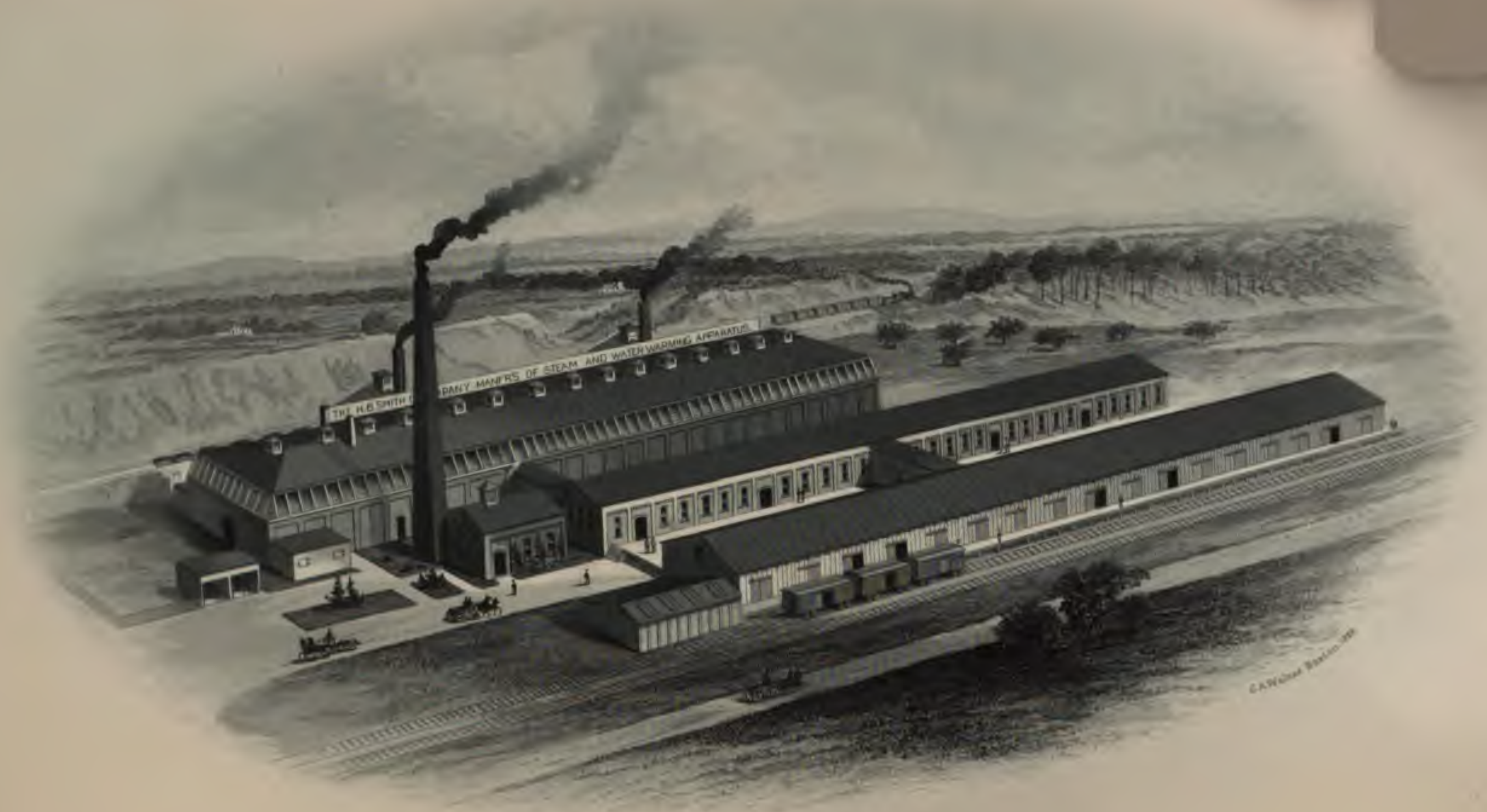
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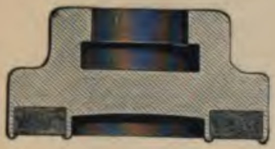

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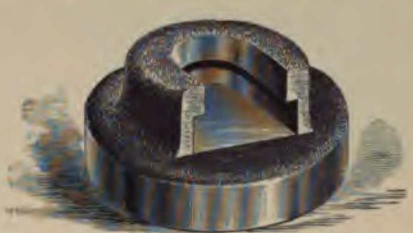

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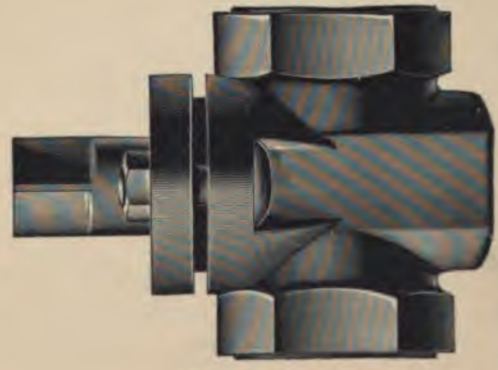

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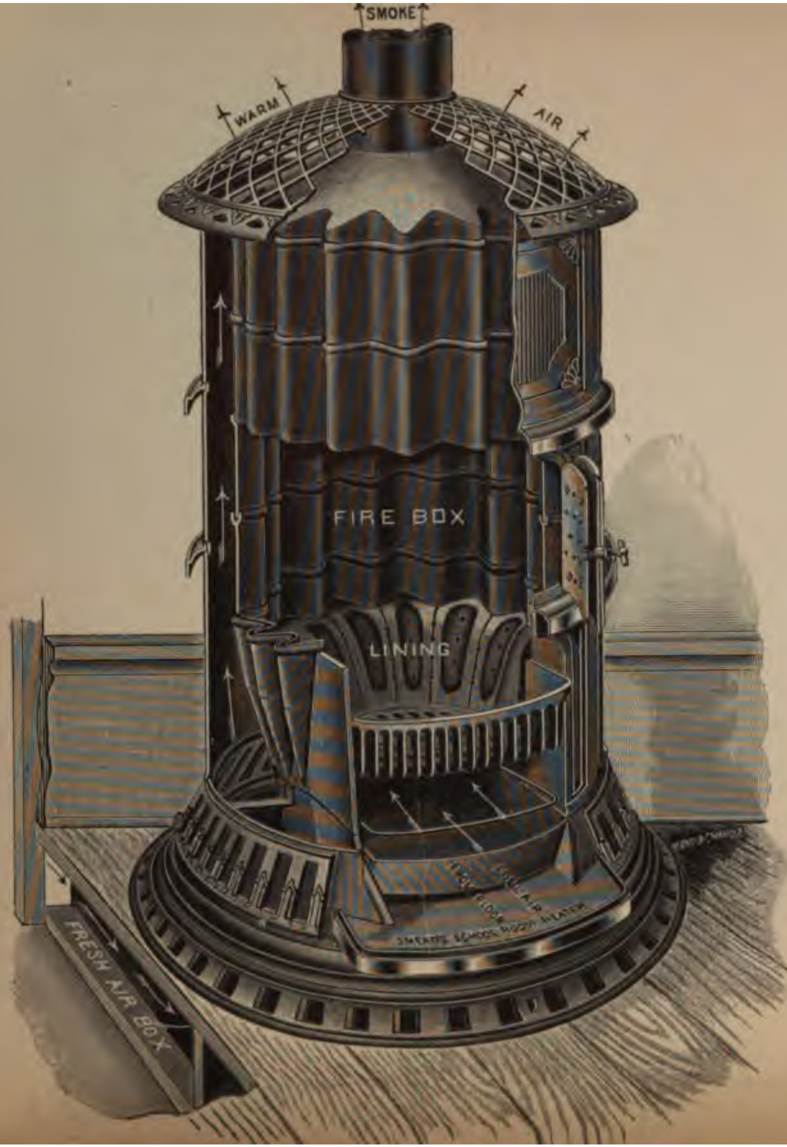
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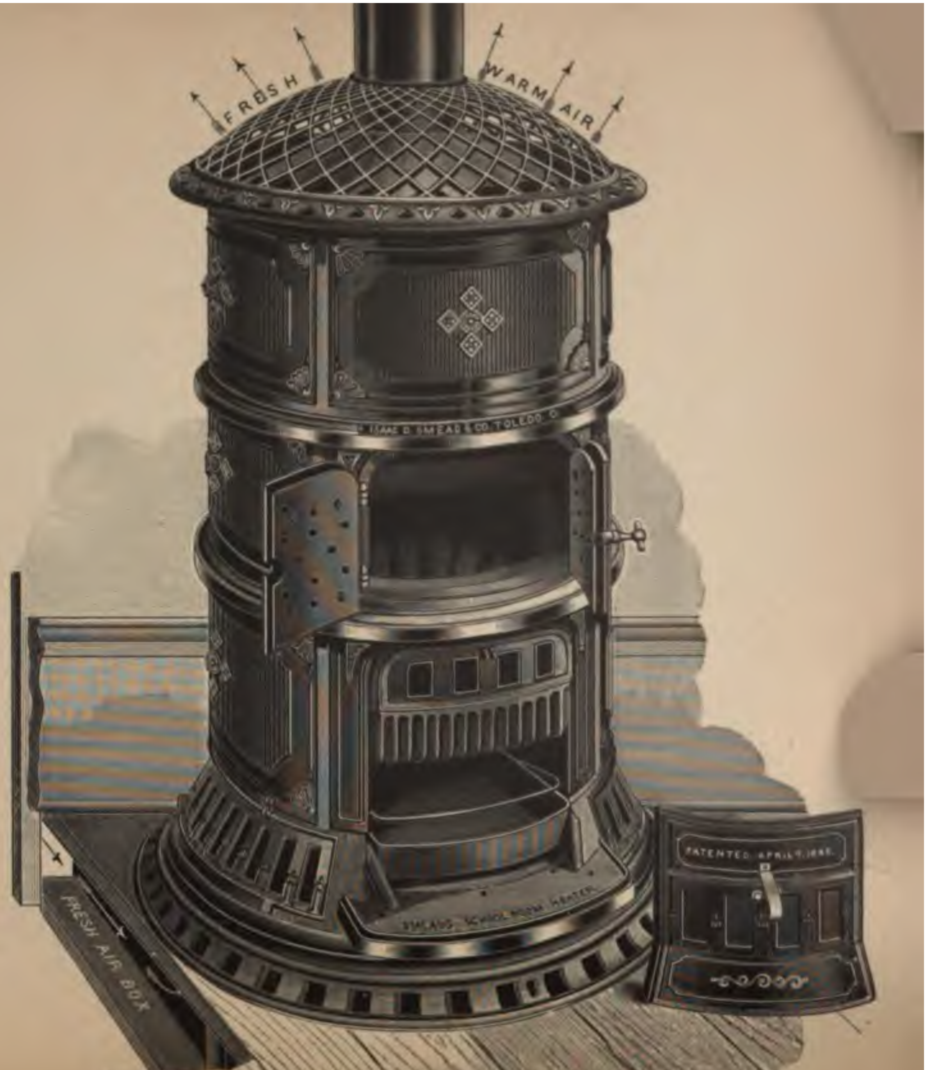
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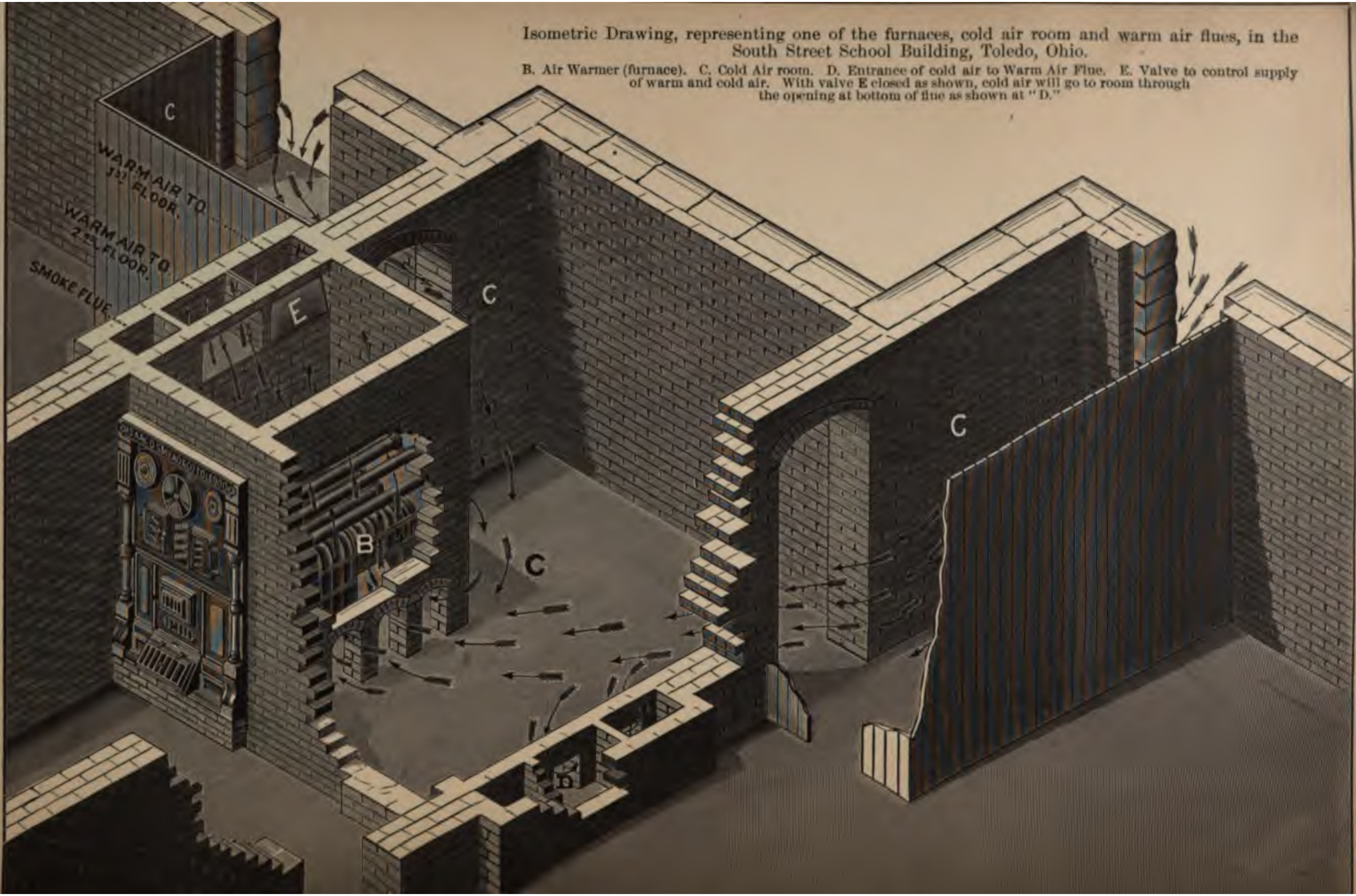

Isometric Drawing, representing one of the furnaces, cold air room and warm air flues, in the South Street School Building, Toledo, Ohio.

B. Air Warmer (furnace). C. Cold Air room. D. Entrance of cold air to Warm Air Flue. E. Valve to control supply of warm and cold air. With valve E closed as shown, cold air will go to room through the opening at bottom of flue as shown at "D."

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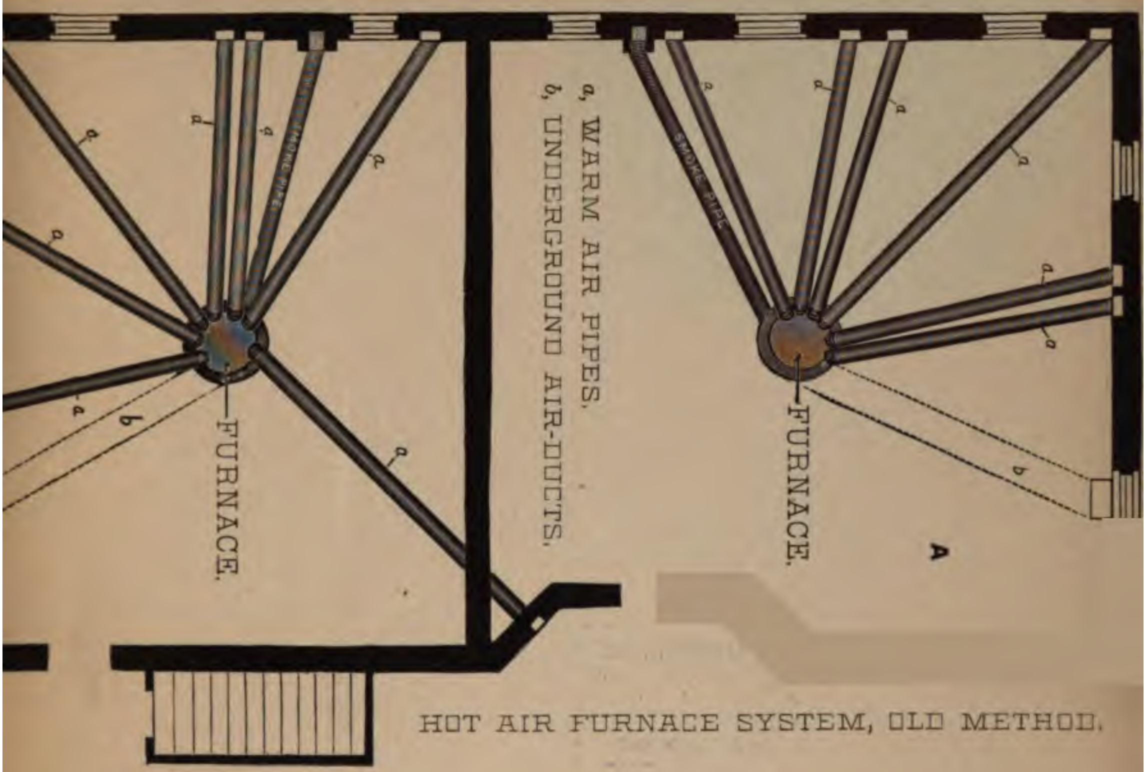
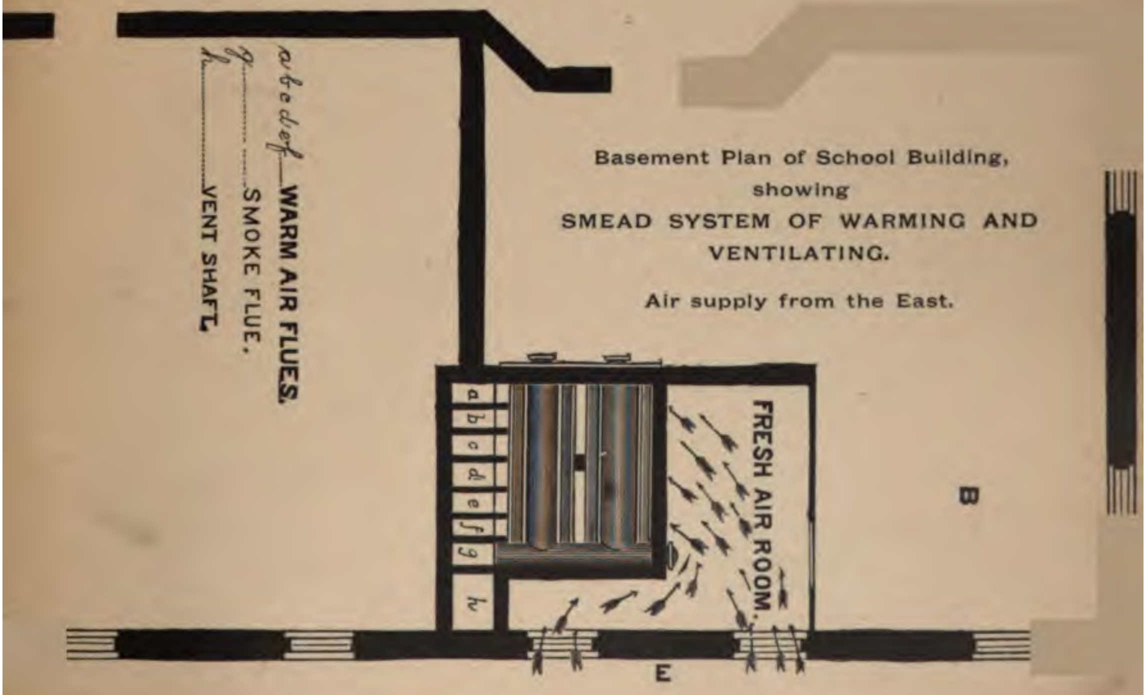


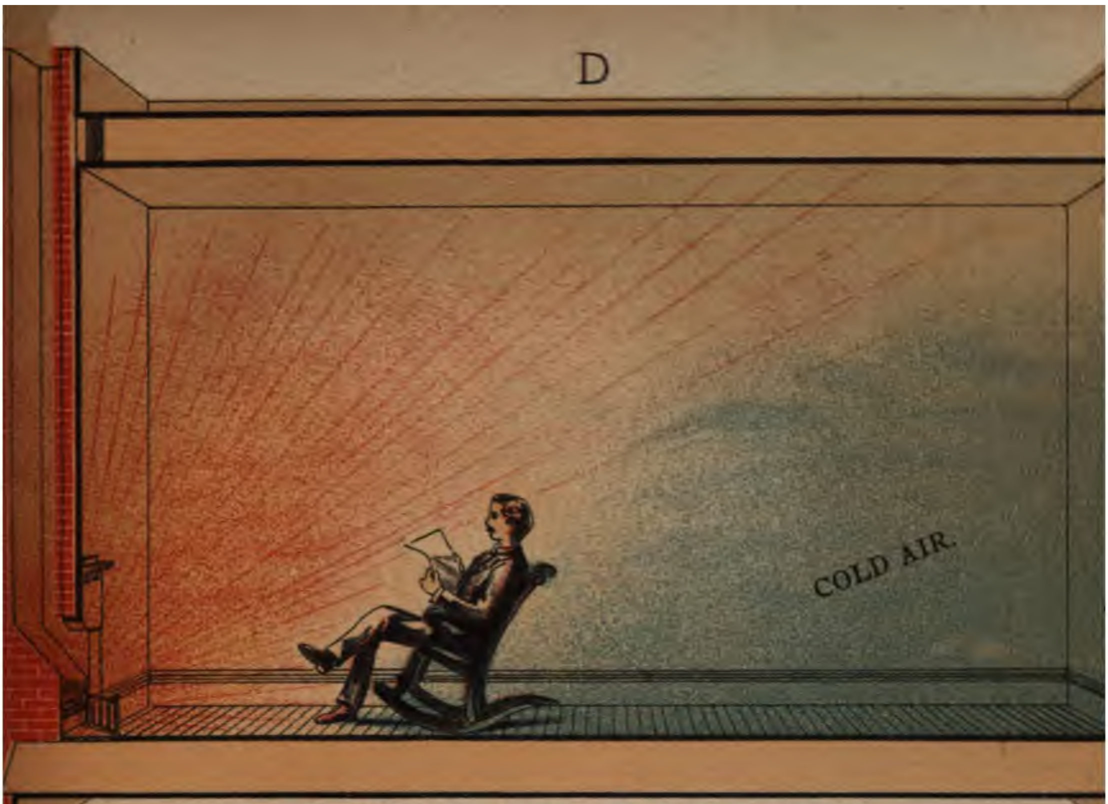
HOT AIR FURNACE SYSTEM, OLD METHOD.



Basement Plan of School Building,
showing
SMEAD SYSTEM OF WARMING AND VENTILATING.

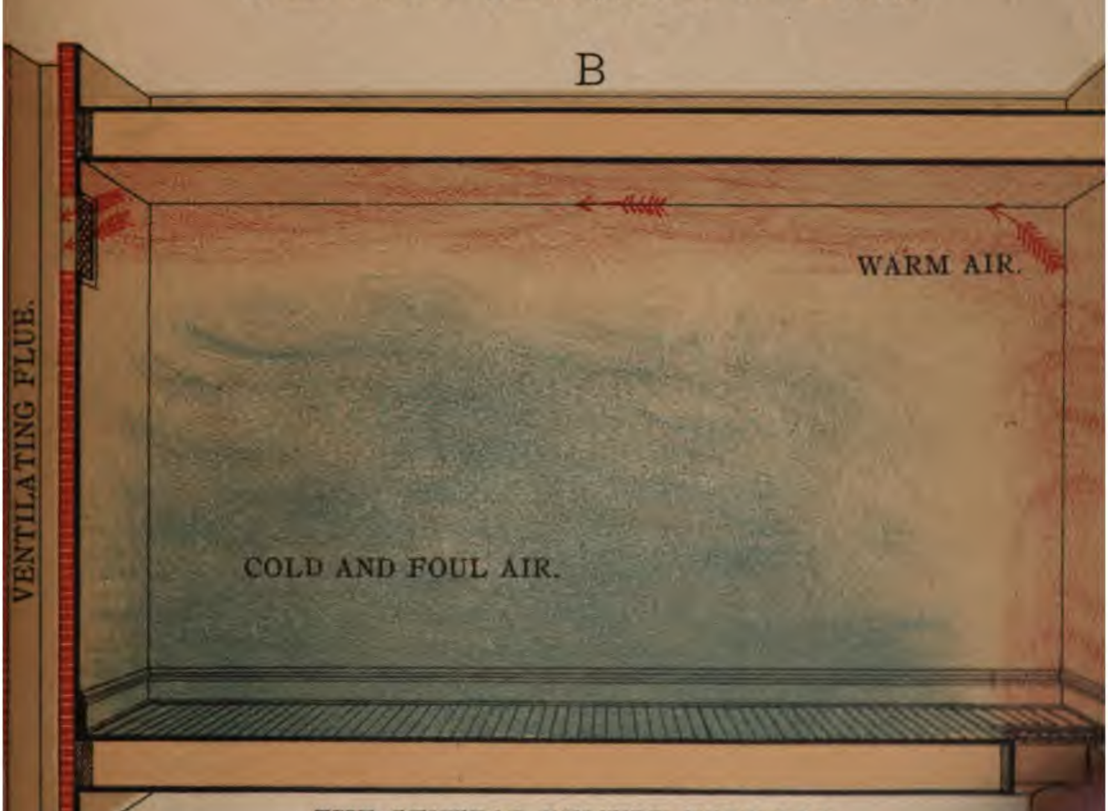
Air supply from the East.

[illegible]



WARMING BY AN OPEN FIRE.

DIRECT RADIATION—(*Exclusively.*)—*Feet cold and head too hot.*

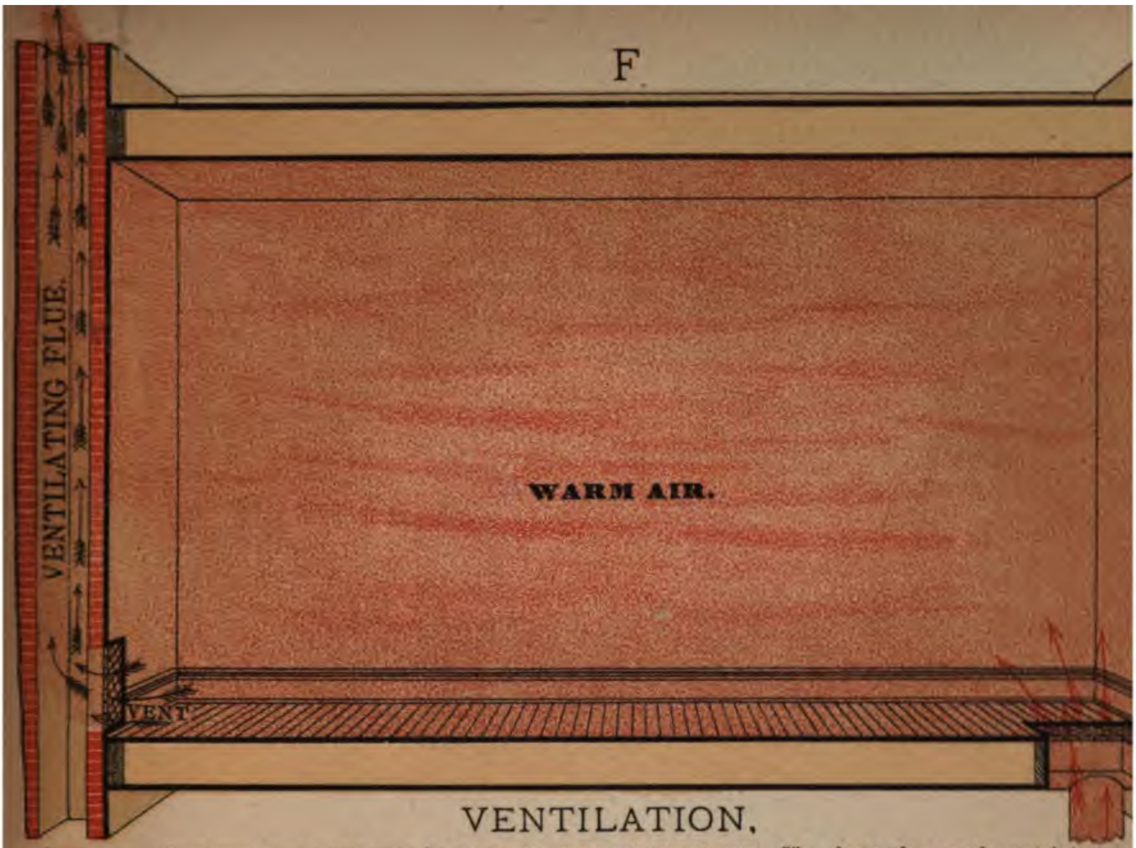

B
WARM AIR.
VENTILATING FLUE.
COLD AND FOUL AIR.

THE GENERAL REMEDY VERY BAD.

Register closed to keep warm, and no other means provided for ventilation, the room soon becomes PRESSED FULL OF HOT AIR, producing headache, discomfort and disease.

[illegible]

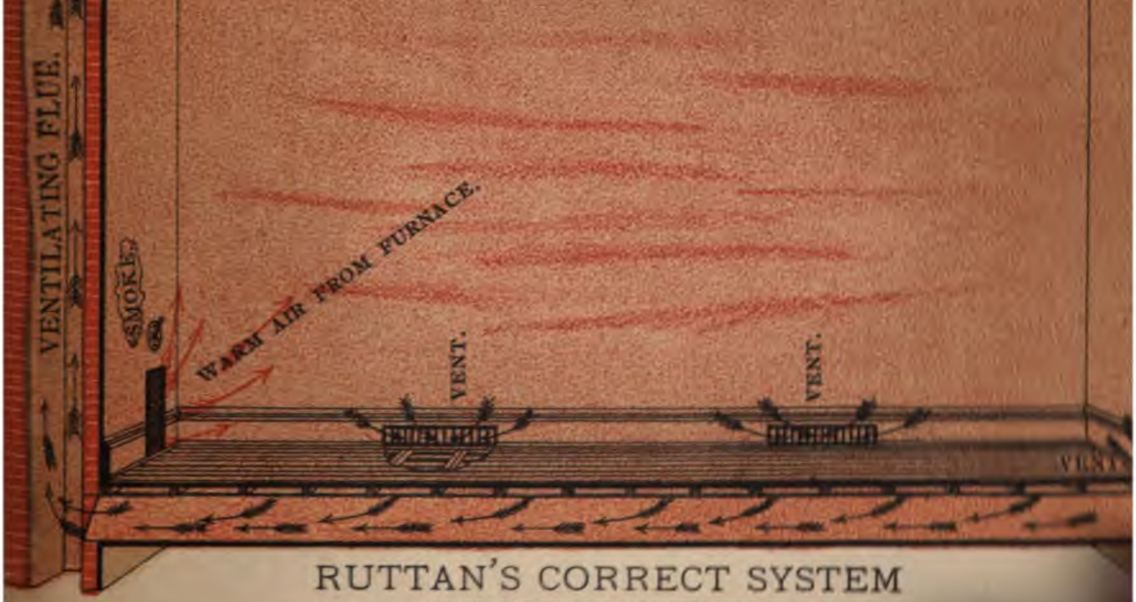
F



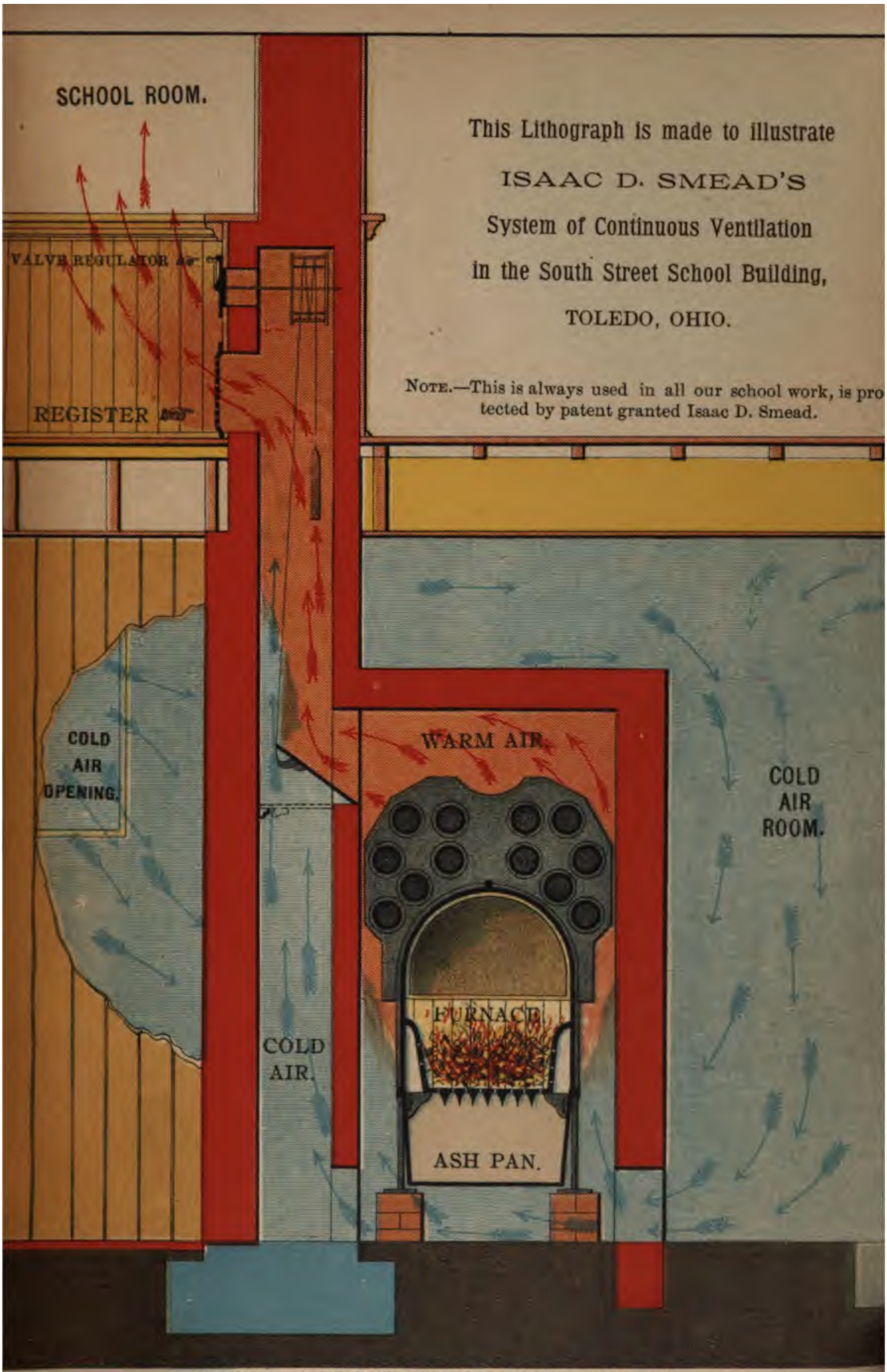
VENTILATION,

CORRECT WHEN HEATING AND VENTILATING BY WARM AIR. The above plan can be put into buildings already constructed, and successfully, provided there is some one in charge who knows how to do it.

G



RUTTAN'S CORRECT SYSTEM
OF WARMING AND VENTILATING.



This Lithograph is made to illustrate

ISAAC D. SMEAD'S

System of Continuous Ventilation

in the South Street School Building,

TOLEDO, OHIO.

NOTE.—This is always used in all our school work, is protected by patent granted Isaac D. Smead.

SECTION, LINE B. B. SHOWING COLD AIR ROOM, FURNACE, AND WARM AIR FLUE.

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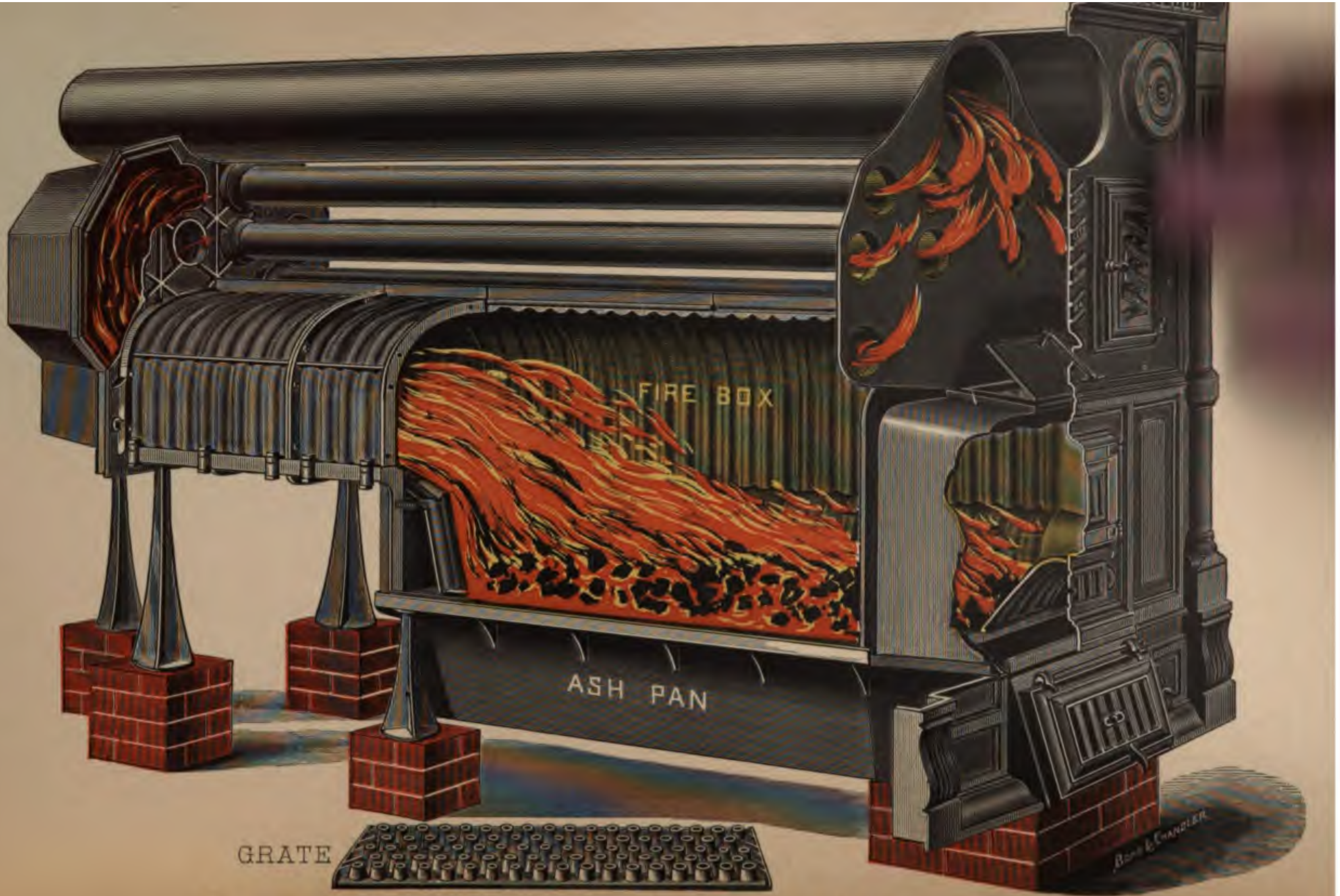
ASTOR, LENOX AND
TILDEN FOUNDATIONS.



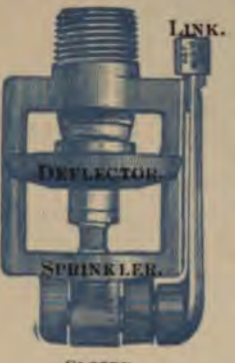
THE RUTTAN-SMEAD TUBULAR AIR WARMER. (1885 PATTERN.)

The largest size is 13 feet long, 6 feet high, 5 feet wide, and weighs about three tons.

[illegible]
[illegible]
ASTOR LENOX AND
TILDEN FOUNDATIONS

FIRE PROTECTION.

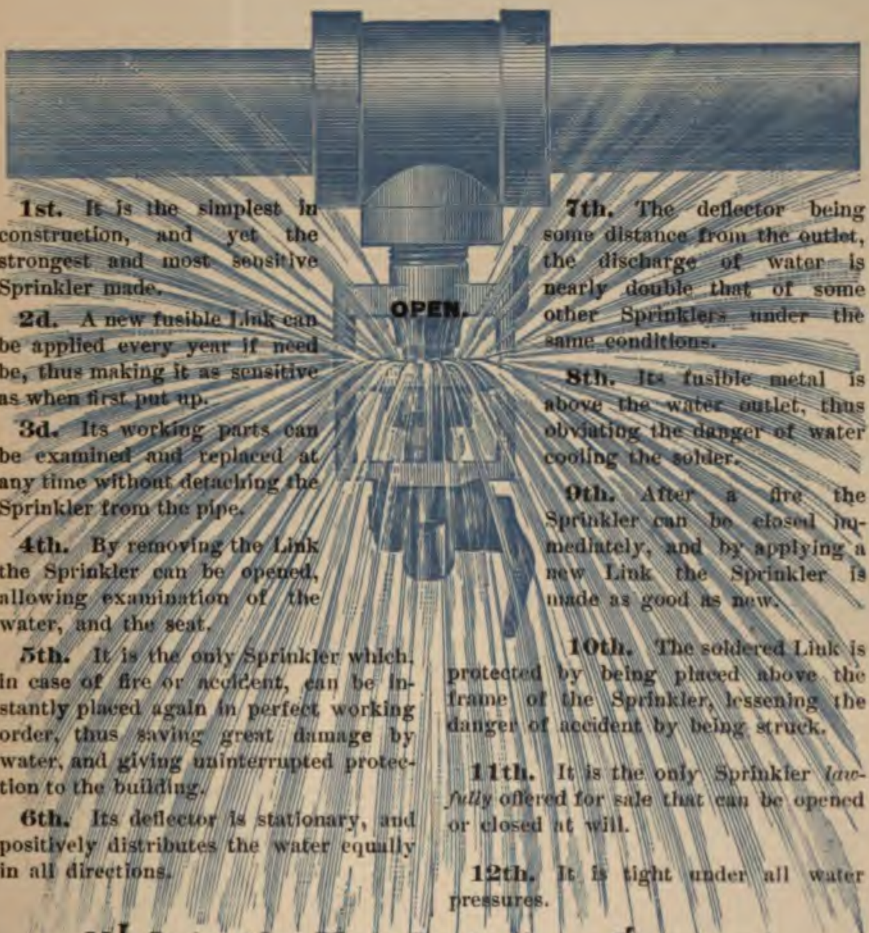
Walworth Automatic Link Sprinklers.



CLOSED.

Patented, Oct. 23, 1883;
Aug. 11, 1885; Sept. 27, 1887.

Dry Pipe System Patented
April 8, 1884.



1st. It is the simplest in construction, and yet the strongest and most sensitive Sprinkler made.

2d. A new fusible Link can be applied every year if need be, thus making it as sensitive as when first put up.

3d. Its working parts can be examined and replaced at any time without detaching the Sprinkler from the pipe.

4th. By removing the Link the Sprinkler can be opened, allowing examination of the water, and the seat.

5th. It is the only Sprinkler which, in case of fire or accident, can be instantly placed again in perfect working order, thus saving great damage by water, and giving uninterrupted protection to the building.

6th. Its deflector is stationary, and positively distributes the water equally in all directions.

7th. The deflector being some distance from the outlet, the discharge of water is nearly double that of some other Sprinklers under the same conditions.

8th. Its fusible metal is above the water outlet, thus obviating the danger of water cooling the solder.

9th. After a fire the Sprinkler can be closed immediately, and by applying a new Link the Sprinkler is made as good as new.

10th. The soldered Link is protected by being placed above the frame of the Sprinkler, lessening the danger of accident by being struck.

11th. It is the only Sprinkler *lawfully* offered for sale that can be opened or closed at will.

12th. It is tight under all water pressures.

Walworth Manufacturing Company,

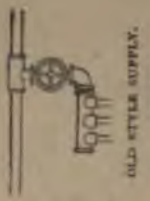
16 OLIVER STREET, BOSTON, MASS.

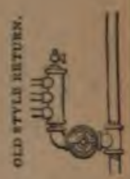
FIGURE No. 16.

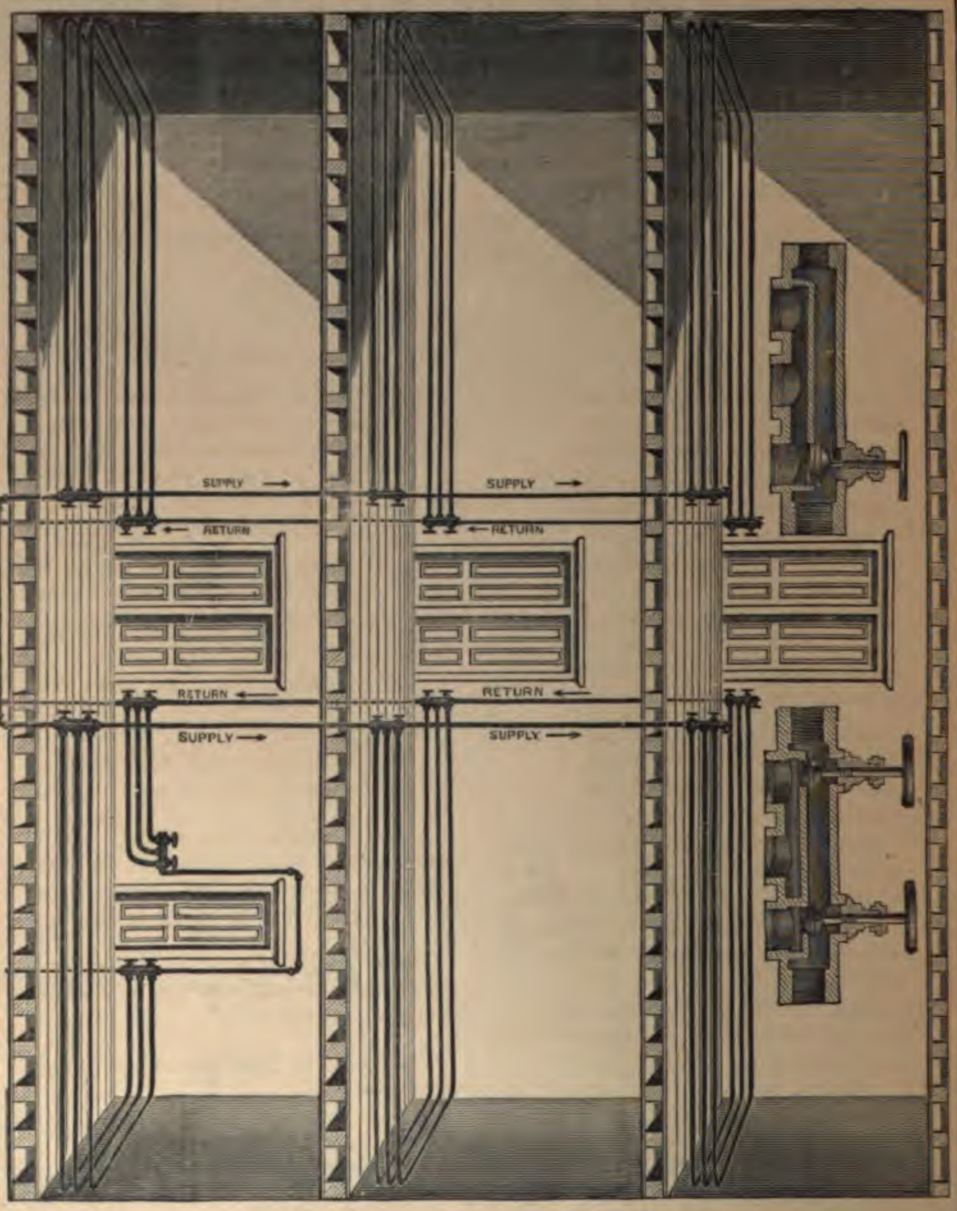
IMPROVED MANIFOLD AND VALVE

For Pipe Circulations and Coils.

MAY BE USED IN EITHER STEAM OR WATER HEATING.







C. C. Walworth's Patent. See also Figure No. 5 (School Heating).

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